INDIANA STATEWIDE TRAVEL DEMAND MODEL UPGRADE

Technical Memorandum: Model Update and Validation

Prepared for the

Indiana Department of Transportation

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I. OVERVIEW

This report documents the updated Indiana Statewide Travel Demand Model (ISTDM) providing technical detail for each of the sequential modeling components. Under the contract with the Indiana Department of Transportation (INDOT) to provide Specialized Planning Services for Statewide Projects, the Scope of Work includes a task that specifies activities to make significant enhancements in features of the ISTDM while updating it to a new 2000 base year. The enhancements include the addition of a significant amount of new network and zones and a re-calibration/validation.

The enhancements were made to the I-69 version of the ISTDM which included all state jurisdictional highways in Indiana, additional network in bordering states, and detailed network in 26-county I-69 study area in Southwestern Indiana. Main features updated from this previous version of the ISTDM are summarized as follows:

- **Network and traffic analysis zone (TAZ) developments.** The network details in Southwestern Indiana in the I-69 version of the ISTDM were expanded to the remainder of the State. INDOT's new Road Inventory Data (RID) for year 2000 was attached to the network and appropriate log mile adjustments were made with addition of local roads. In accordance with the network details, TAZ structure was refined by adding a significant number of TAZs within Indiana. These refinements in the network and TAZ data improved the model's overall reliability and accuracy.

- **Traffic signals.** The location of traffic signals along with priority of signal approaches and number of upstream signals was coded statewide in the network. This information associated with traffic signals was used for estimating more realistic link impedances.

- **New procedures for estimating free-flow speeds and capacities.** A new procedure was developed to estimate free-flow speeds based on detailed geometric features obtained from the RID and reanalysis of the speed survey conducted for the I-69 Tier 1 Evansville to Indianapolis Environmental Impact Study. Another procedure was created to estimate link capacities based on the Highway Capacity Manual 2000 (HCM 2000). These two link impedances were subsequently adjusted for signal delays.

- **Development of stratification curves.** Stratification curves which breakout total households into cross-classification categories based on average zonal characteristics (average household size, average auto ownership, average income) were developed and employed to give trip rates sensitivity to changes in household size, auto ownership and household income over time.

- **Trip generation models.** The base year trip generation models were updated based on 2000 Census data. Trip production rates were refined to account for area types and trip attraction rates were re-estimated using updated land use data including new employment categories. Long purpose trips included internal zones in bordering states and their production models were cross-classified by household income and vehicle availability.

- **Feedback Loop.** Trip distribution adopts a single feedback of congested times to the gravity model. An initial gravity model is implemented on free-flow speeds and the resulting trip tables are assigned to the network. This initial assignment produces congested link speeds that are then used as inputs into the gravity model to redistribute trips based on congested travel times.

- **Gravity model factors.** New friction factor curves were calibrated to address the refined transportation network and smaller zone sizes within Indiana. Friction factors for the long trip purpose were developed to distribute trips between all study area internal TAZ's including areas external to Indiana. K-factors were validated to account for factors not explained by friction factors.

- **Mode choice model.** Mode shares for HBW, HBO, and NHB trip purposes were reviewed and updated to account for area type based on the 1995 Indiana Travel Survey and/or 2001 NHTS data. The multinomial logit model for the long trip purpose was re-validated to account for changes in the travel model network and TAZ layers.

- **Truck models.** Freight and non-freight trucks were estimated separately. For freight trucks, base year 1993 truck trip tables from the Indiana University study were factored up to year 2000 levels by commodity group. For future forecast, future year growth factors were applied by commodity group to be more sensitivity to changes in land use as well as to incorporate the effects of changes in worker productivity over time. Non-freight truck trip tables were estimated using ODME procedures using link freight loadings subtracted from INDOT link truck counts.

- **Trip assignment.** Trip assignment process was changed from free-flow based assignment of trucks as a "pre-load" to "simultaneous multi-modal multi-class assignment". Two phases of assignment are implemented: The first phase is based on trip tables obtained from free-flow speed and the second phase uses trip tables re-estimated for congestion. Multiple volume-delay functions were specified by functional classification based on extensive experimentation with the functions made during model validation.

The first part of this report is devoted to describing network and TAZ data development. Then, the new speed and capacity estimation procedures are explained in detail. Modeling components of the upgraded ISTDM are described with associated tables and figures. Later, model validation results are presented with key error statistics such as loading error, VMT error, and percent root mean square error. At the end of this report, features of a post-processor developed to estimate various performance measures from the ISTDM are presented in detail.

Throughout this report, the previous version of the ISTDM is referred to as "the I-69 ISTDM" and the enhanced model this report presents here as "the upgraded ISTDM".

II. MODEL AREA

The ISTDM includes all 92 counties in Indiana and encompasses parts of neighboring States, with Indianapolis being the center of the model area. Screenlines are placed on the Indiana State border to capture and validate incoming and outgoing traffic on the State border. Major arteries that carry regional traffic include I-65, I-74, I-70, I-69, I-80, I-64, US 31 and US 41 in Indiana, I-57 in Illinois, I-71 in Kentucky, I-75 in Ohio, and I-94 in Michigan. **Figure 1** shows the ISTDM model area along with highlights of major roadways.

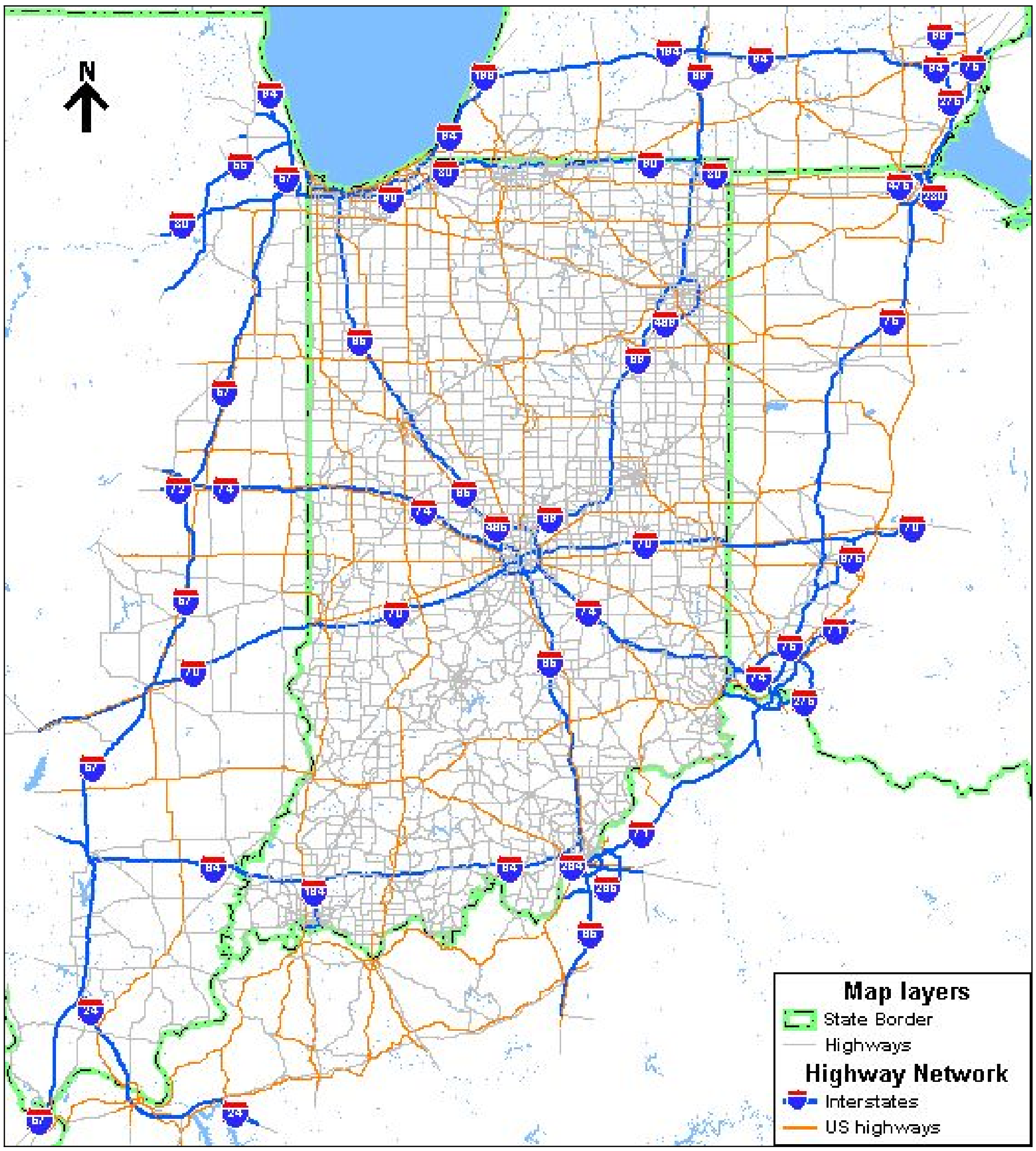


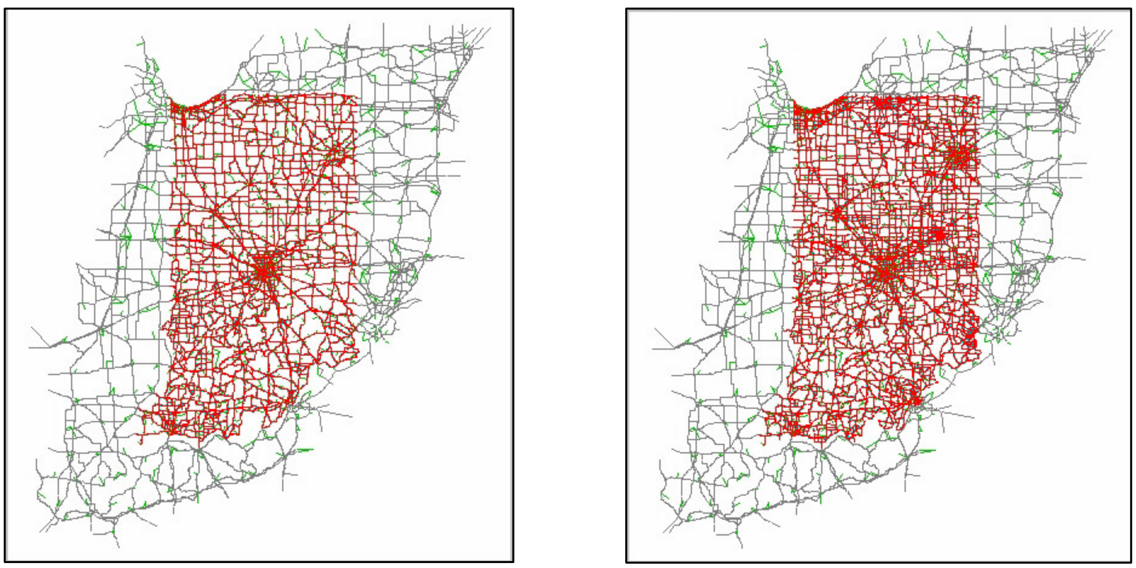
Figure 1. ISTDM Model Area
(**Source**: Bernardin, Lochmueller & Associates, Inc., 2004)

III. NETWORK DEVELOPMENT

The current ISTDM highway network was developed based on the I-69 ISTDM network. The I-69 network included all state jurisdictional highways and additional county roads and local streets in 26 counties in southwestern region of the State. This network detail had the effect of smoothing assigned volumes on roads with higher functional classifications and laid the groundwork for a similar refinement of the ISTDM in the balance of the state.

A. NETWORK REFINEMENTS

The upgraded ISTDM expands the network details to the remainder of the State, so it includes county roads and local streets for all 92 counties. The base year network consists of over 19,500 links (or 11,200 road miles) for state jurisdictional highways and over 11,500 links (or 7,800 road miles) for local roads in Indiana. The whole model network, including major highways in bordering states, is comprised of 34,500 links (or 29,300 road miles). This network is conjoined with traffic analysis zones via 10,300 centroid connectors that load traffic onto appropriate loading points in the network. **Figure 2** shows increased network details in the upgraded ISTDM network in comparison with the I-69 version.



I-69 ISTDM | Upgraded ISTDM

Figure 2. Increase in Network Details in the Upgraded ISTDM
(**Source**: Bernardin, Lochmueller & Associates, Inc., 2004)

As network details were added to the network, links in the network were inevitably split into shorter links due to additions of local roads and more centroid connectors. Thus, it was necessary to adjust existing log-miles in accordance with the network improvement. A special program was written to adjust log-miles in an orderly fashion based on the length of the shorter links and their directions.

As the network is added with more links and TAZ structure is refined accordingly, centroid connectors should be put at appropriate loading points for the detailed TAZs. To find preliminary loading points of centroid connectors, a centroid connector placement tool was developed. In this tool, the maximum number of connectors per zone was limited to three. The program makes sure that connections are made to different facilities while disallowing connections to any facilities with full or partial access control. It finds the nearest facility and makes connection if access control allows. Then, it rotates 120 degree and looks for a new facility and ensures that none of the connections is made to the same facility. It continues through a full 360 degree rotation to complete the connection procedure. The procedure is fully automated and was useful to do initial placement of centroid connectors to over 30,000 links in the network. The initial location of centroid connectors was later reexamined and adjusted during model validation through judgment based on actual local road connections and/or major loading points.

B. NETWORK DATA

INDOT's new Road Inventory Data for year 2000 (RID 2000) was attached to the upgraded model network. The attachment was accomplished by means of TransCAD's JOIN/FILL functions using a unique field (DRK) that is common to both the RID 2000 database and the model network. The links that were not attached were identified and manually matched. Main RID 2000 attributes incorporated in the model network includes:

- Lanes, lane widths,
- Shoulders, shoulder widths,
- Medians, when present, and median width,
- Access control types,
- Total traffic and truck count data, and
- Functional classifications.

For details about network data attributes, refer to "Technical Memorandum: Model Users Guide".

C. TRAFFIC SIGNAL PLACEMENT

The I-69 ISTDM network included traffic signals in I-69 study area to derive more realistic link impedances by considering signal delays. The upgraded ISTDM network now adds traffic signals throughout the state. The location of signals as well as priority of signal approaches and number of up-stream signals was coded in the whole Indiana network, resulting in almost 3,900 traffic signals statewide approximately 2,600 of which are on state jurisdictional highways and the rest on local facilities. The signals were placed in the network using two data sources. First, INDOT point layer for traffic signals on state jurisdictional system circa 1997 was tagged into the network. Signals on local jurisdictional roads were located by means of INDOT's geo-coded crash database for 1997 through 1999 using a flag field which identified the presence of a traffic signal. This methodology covered all roads and all signals where there was a crash of any type between 1997 and 1999. While it is reasonable to assume there are a few signals missing, the crash database is the best available source for signals on local roads at the moment. The traffic signal locations coded on both state and local jurisdictional systems are presented in **Figure 3**.

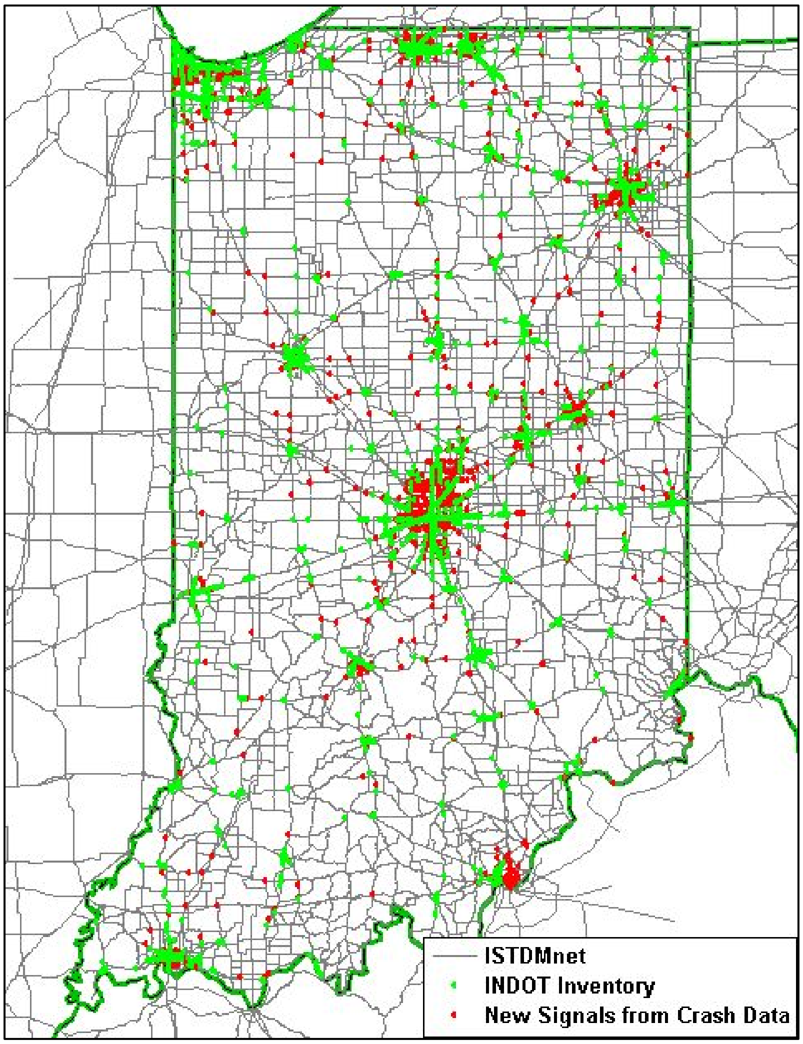


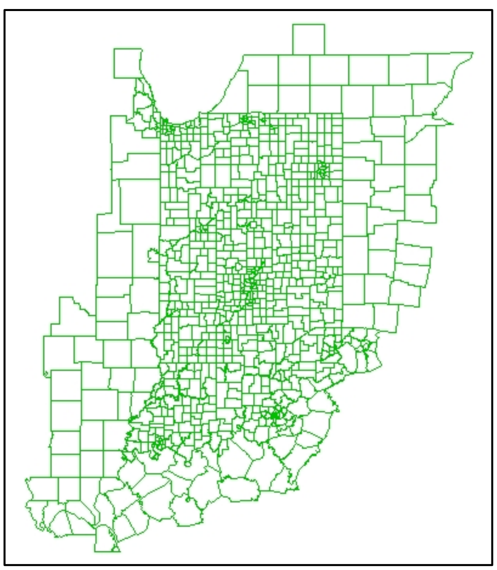
Figure 3. Traffic Signals in the ISTDM Network
(**Source**: Bernardin, Lochmueller & Associates, Inc., 2004)

IV. TAZ DEVELOPMENT

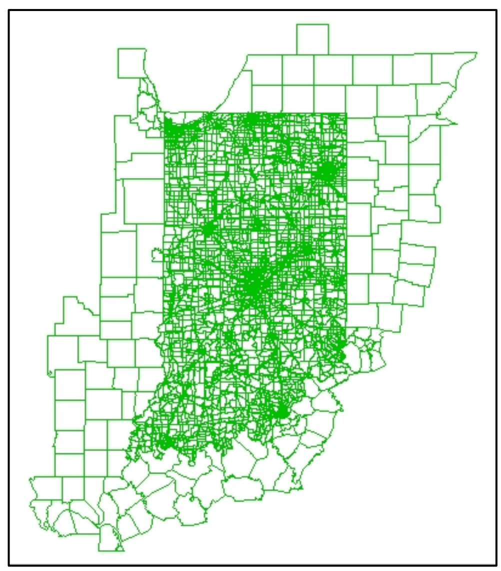
The ISTDM represents traffic analysis zones both within (internal) and outside (external) the State of Indiana. External area networks and zones are represented using less detail than areas within Indiana. Zones adjacent to the model area are represented using external stations without zonal boundaries.

A. TAZ REFINEMENTS

One of the most significant improvements to the ISTDM is a new, much refined zone system that generally conforms to the roadway network. It is important that TAZ boundaries conform to the roadway network whenever possible in travel models so that each TAZ produces and loads vehicle trips on the network in a realistic and controlled way. Limitations in available data, computer file size and processor speeds prohibited general agreement between the TAZ and network in previous versions of the ISTDM. However, these obstacles were able to be overcome in this new version. In addition to conforming to the network, the new zones can still be aggregated to old zones and to the CTPP zones. The new TAZ structure was developed using a GIS-based process. The process used three layers: roads, old TAZs, CTPP boundaries. A minimum area for zones was set and a GIS-DK tool was written to eliminate "slivers". Census blocks were merged to the new area using ArcView. The upgraded ISTDM is represented by a total of 4,720 TAZs, a huge increase in zone detail from 844 TAZs in the I-69 ISTDM. **Figure 4** compares the zone structure of these two model networks.



I-69 ISTDM



Upgraded ISTDM

Figure 4. Increase in TAZ Details in the Upgraded ISTDM
(**Source**: Bernardin, Lochmueller & Associates, Inc., 2004)

B. TAZ DATA

Each zone is characterized by 50 zonal attributes. These attributes include TAZ number and detailed categorization of population, households, vehicle ownership, mean household income, grade school enrollment, university enrollment and employment by category. The TAZ layer also contains a number of fields populated by trip production and attraction estimates by the model's trip generation procedures.

For details about TAZ data attributes, refer to "Technical Memorandum: Model Users Guide".

V. FREE-FLOW SPEED ESTIMATION

In the I-69 Tier 1 Study a free-flow speed table was constructed based on the speed survey implemented in 26-county southwestern Indiana at 64 survey locations. This table derived free-flow speeds based on FHWA functional classification, posted speed and number of lanes of the facility. Instead of relying on traditional simple speed table, this table greatly improved the level of accuracy in arriving at link free-flow speeds.

However, the speeds estimated using this table are heavily reliant on roadways' functional classification, which is to a certain degree judgmental, instead of using actual physical roadway types. Even though a high correlation exists between the functional classification and the roadway type, it is still vulnerable to mismatch between the two and to uncertainty of the functional classification for proposed facilities. To prevent possible biasing of free-flow speeds by roadways' functional classification, a new approach was sought so that free-flow speed estimation is now based on the facility type of the roadway.

In this new approach, the original I-69 speed survey database was revisited. In each survey location, the roadway's geometric and functional characteristics were identified. Facility type was defined as a function of number of lanes, divided/undivided, area type and access control type. In addition to the facility type, a speed limit posted on each location and hourly traffic volumes were recorded. Based on free-flow conditions defined based on hourly traffic volume in the Highway Capacity Manual (HCM) 2000, the database was narrowed down, so that it only represents free-flow conditions.

With the selected speed and geometric data, a test using Analysis of Variance (ANOVA) technique was implemented to check if there is a significant difference in speeds between 2-lane 2-way and 4-plus lane facilities. The test showed a statistically significant difference in speeds between these two facilities. Following the tests, for each unique facility type, a relationship between posted speed and free-flow speed was identified using non-linear regression analysis.

Table 1 lists the nonlinear formula developed for major facility types. The speeds for other minor variations in facility type such as one-way streets were derived from these formula based on similarity in geometric and functional characteristics of the roadway.

Table 1. Free-Flow Speed Estimation Formula

Area Type	Free-Flow Speed [1, 2]	Condition	Note
2-lane 2-way undivided highways			
Rural	$0.009751 \cdot \mathrm{PSPD}^2 + 30.03397$	$25 \le \mathrm{PSPD} \le 55$	No or Partial Access Control
	25	PSPD < 25	
Suburban	$117.640917 \cdot \mathrm{PSPD}^{0.0015+0.001279 \cdot \mathrm{PSPD}} - 98.065483$	$25 \le \mathrm{PSPD} \le 55$	
	25	PSPD < 25	
Urban	$6.189 + 0.9437 \cdot \mathrm{PSPD}$	$25 \le \mathrm{PSPD} \le 55$	
	25	PSPD < 25	
2-lane 2-way divided highways			
Rural	$\left(0.000017 \cdot (\mathrm{PSPD} - 72.323105)^2 + 0.019702\right)^{-1} + 19.835323$	$25 \le \mathrm{PSPD} \le 55$	No Access Control
	25	PSPD < 25	
Suburban	$3.180682 \cdot \mathrm{PSPD}^{0.857638} - 84.105587 \cdot e^{-41.803252 / \mathrm{PSPD}}$	$25 \le \mathrm{PSPD} \le 55$	
	25	PSPD < 25	
Urban	$\left(0.119687 - 0.023365 \cdot \ln(\mathrm{PSPD})\right)^{-1} + 0.373821 \cdot \mathrm{PSPD}$	$25 \le \mathrm{PSPD} \le 55$	
	25	PSPD < 25	
Multilane undivided highways			
Rural	$\left(0.000017 \cdot (\mathrm{PSPD} - 72.323105)^2 + 0.019702\right)^{-1} + 19.835323$	$25 \le \mathrm{PSPD} \le 65$	
	25	PSPD < 25	
Suburban	$3.180682 \cdot \mathrm{PSPD}^{0.857638} - 84.105587 \cdot e^{-41.803252 / \mathrm{PSPD}}$	$25 \le \mathrm{PSPD} \le 55$	
	25	PSPD < 25	
Urban	$\left(0.119687 - 0.023365 \cdot \ln(\mathrm{PSPD})\right)^{-1} + 0.373821 \cdot \mathrm{PSPD}$	$25 \le \mathrm{PSPD} \le 55$	
	25	PSPD < 25	
Multilane divided highways			
Rural	$2.836165 \cdot \mathrm{PSPD} - 0.071256 \cdot \mathrm{PSPD}^2 + 0.000744 \cdot \mathrm{PSPD}^3$	$25 \le \mathrm{PSPD} \le 50$	No or Partial Access Control
	$16.0359 + 0.8223 \cdot \mathrm{PSPD}$	$50 < \mathrm{PSPD} \le 65$	
	25	PSPD < 25	
Suburban	$\left(0.000071 \cdot (\mathrm{PSPD} - 64.166165)^2 + 0.035258\right)^{-1} + 9.061039 \cdot \ln(\mathrm{PSPD})$	$25 \le \mathrm{PSPD} \le 55$	
	25	PSPD < 25	
Urban	$\left(0.081714 - 0.016217 \cdot \ln(\mathrm{PSPD})\right)^{-1}$	$25 \le \mathrm{PSPD} \le 55$	
	25	PSPD < 25	
Full access controlled highways			
	64.00	PSPD = 55	
	67.06	PSPD = 60	
	70.21	PSPD = 65	
	73.30	PSPD = 70	

Note: [1] Free-flow speeds in mph, [2] PSPD: Posted speeds in mph

Source: Bernardin, Lochmueller & Associates, Inc., 2004

VI. CAPACITY ESTIMATION

The common practice for estimating capacities applied in most travel models ascribes a roadway capacity based on a simplified link capacity system that in many cases over or underestimates the true capacity of the roadway. Peak-hour roadway capacities of the upgraded ISTDM network were estimated based on the HCM 2000 procedures. Then, daily capacities were calculated by factoring up the hourly capacities using the inverse of K-factors. The peak-to-daily factors (i.e., inverse of K-factors) for rural highways were borrowed from the Kentucky Transportation Cabinet (KYTC)'s K-factors by functional classification. For urban highways, a factor of 10 was uniformly used for all urban classifications.

In the new capacity estimation procedure, detailed link data on geometric and functional characteristics incorporated in the network were utilized for improved estimates of link peak-hour capacities. First, all links in the model area were set to "maximum hourly service flows" as specified in HCM with respect to their facility type. Then, the maximum service flows were adjusted to "hourly service flows" based on several limiting factors. These factors included: right-shoulder lateral clearance, heavy vehicles, driver population, lane width, number of lanes, interchange density, median type, access points, and directional distribution.

A significant effort was given to develop these limiting factors from HCM 2000. For each of these factors, the HCM provides adjustments (or reductions) in free-flow speed that reflect the negative effect of the factor. The reductions are determined based on geometric features of the roadway. For example, for adjustments for lateral clearance for freeways, two geometric variables (right-shoulder lateral clearance and number of lanes) are cross-referenced to estimate the reduction of free-flow speed. These adjustments are then applied to the base free-flow speed to obtain an adjusted free-flow speed that takes into consideration the unique physical conditions of the roadway. Exhibit 23-5 in HCM 2000 show the adjustments.

As the first step to derive the capacity reduction factors, a possible range of free-flow speeds was set based on facility type. In the above example for freeways, speeds from 55 mph to 75 mph in an increment of 2.5 mph were used. For each combination of these preset speeds and the geometric variables, a ratio of the reduced free-flow speed to the base (unadjusted) free-flow speed was calculated. This process resulted in a two-dimensional table (i.e., one dimension containing a range of free-flow speeds and the other containing a geometric variable) that is populated with the ratios, or free-flow speed reduction factors. An example of this table is shown in **Table 2**.

Given the assumption that the service flow is directly proportional to the free-flow speed, it follows that the maximum service flow can be adjusted to the service flow with the same reduction percentage as the free-flow speed reduction factor. In this way the speed reduction factors were used to adjust the maximum hourly service flows to derive the hourly service flows.

The two-dimensional table can be represented in a 3-dimensional space as shown in **Figure 5**. The factors in this space were then smoothed by curve fitting the factors using bi-factor nonlinear regression techniques. As an example, **Table 3** lists curve-fitted formulas for capacity reduction factors for lateral clearance. This procedure was applied to other capacity adjustment factors such as adjustments for access point densities, lane widths, etc.

Table 2. Capacity Reduction Factors for Freeways (for 2 lanes in one direction)

right-shoulder lateral clearance (ft)	reduction in free-flow speed (mph)	free-flow speed (mph)								
		75	**72.5**	**70**	**67.5**	**65**	**62.5**	**60**	**57.5**	**55**
6	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.6	0.9920	0.9917	0.9914	0.9911	0.9908	0.9904	0.9900	0.9896	0.9891
4	1.2	0.9840	0.9834	0.9829	0.9822	0.9815	0.9808	0.9800	0.9791	0.9782
3	1.8	0.9760	0.9752	0.9743	0.9733	0.9723	0.9712	0.9700	0.9687	0.9673
2	2.4	0.9680	0.9669	0.9657	0.9644	0.9631	0.9616	0.9600	0.9583	0.9564
1	3	0.9600	0.9586	0.9571	0.9556	0.9538	0.9520	0.9500	0.9478	0.9455
0	3.6	0.9520	0.9503	0.9486	0.9467	0.9446	0.9424	0.9400	0.9374	0.9345

Source: Bernardin, Lochmueller & Associates, Inc., 2004

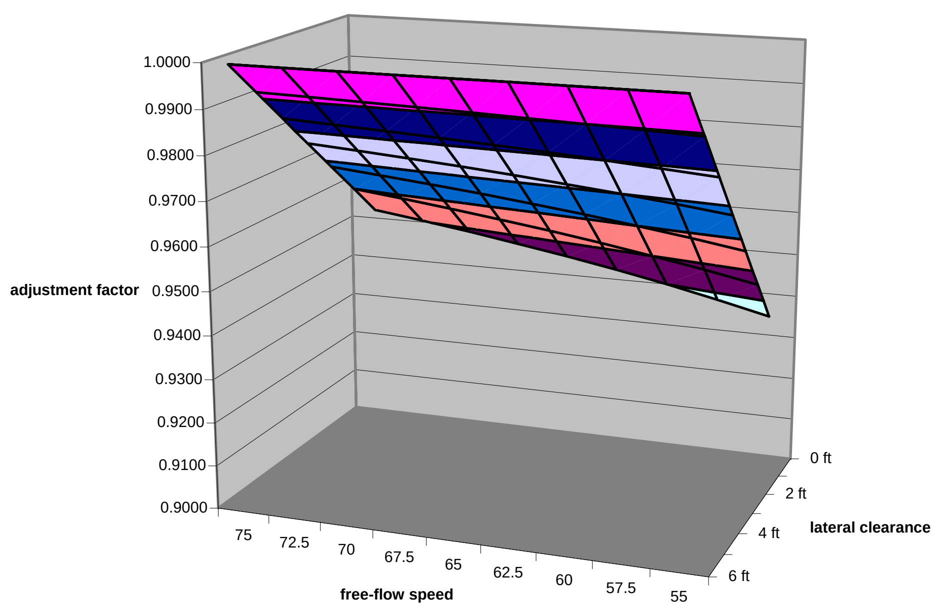


Figure 5. Capacity Reduction Factors for Lateral Clearance (Freeways)
(**Source**: Bernardin, Lochmueller & Associates, Inc., 2004)

Table 3. Capacity Reduction Factors for Lateral Clearance

Facility Type	Reduction Factor	Condition
Interstates and Freeways		
2 lanes in one direction	$\frac{-6.00001+\text{RSLC}}{0.0001+1.66667*\text{FFSpeed}}+1$	Min. 0.9345
3 lanes in one direction	$\frac{-5.99999+\text{RSLC}}{-0.00084+2.50001*\text{FFSpeed}}+1$	Min. 0.9564
4 lanes in one direction	$\frac{-6.00001+\text{RSLC}}{-0.00002+5*\text{FFSpeed}}+1$	Min. 0.9782
5+ lanes in one direction	$\frac{-6.00002+\text{RSLC}}{0.00371+9.99994*\text{FFSpeed}}+1$	Min. 0.9891
Multilane Highways		
4 total lanes	$\frac{1095.74797+\text{FFSpeed}}{1280.33942+6.53454*\text{RSLC}^2}+0.03975*\text{RSLC}$	Min. 0.8800
6 total lanes	$\frac{1485.4381+\text{FFSpeed}}{1660.34815+3.0981*\text{RSLC}^2}+0.02166*\text{RSLC}$	Min. 0.9133
Two-lane Highways		
Shoulder width < 2 ft	$1.20306*\text{FFSpeed}^{(0.27207-0.08633*\ln(\text{LW}))}-\frac{7.09882}{\text{LW}}$	Min. 0.8400
Shoulder width < 4 ft	$1.43621*\text{FFSpeed}^{(0.26354-0.09366*\ln(\text{LW}))}-\frac{8.06484}{\text{LW}}$	Min. 0.8800
Shoulder width < 6 ft	$1.58362*\text{FFSpeed}^{(0.24881-0.09472*\ln(\text{LW}))}-\frac{8.34158}{\text{LW}}$	Min. 0.9125

Note: RSLC: right-shoulder lateral clearance (ft)
FFSpeed: free-flow speed (mph)
LW: lane width (ft)

Source: Bernardin, Lochmueller & Associates, Inc., 2004

VII. DELAYS ON INTERRUPTED FACILITIES

Although the traditional name for a conventional travel model is a travel demand model, a good model requires as much attention to the specification of supply, or capacity, as to demand. It is therefore important that the free-flow speeds and roadway capacities estimated in the previous steps are adjusted to account for delays associated with traffic signals. The adjustments were made to roadway segments directionally according to the methodology described below. This methodology is taken from the HCM 2000 and replaces an earlier method of estimating signal impedance based on the probability of stop which was implemented in the I-69 version of the model. The new methodology has several significant advantages and has consistently yielded superior assignments with less calibration adjustments in several models. The two main advantages of the new methodology are its ability to factor in the reduced likelihood of stopping in a series of signals due to synchronization between them and its ability to distinguish between different approaches to the same signal which may be associated with more or less impedance depending whether the approach is on a mainline facility or a cross street.

As explained in Chapter III in this report, traffic signals are coded in the network in terms of their locations, approach prioritization and number of upstream signals. Regarding the approach prioritization, if the approach to the signalized intersection is a higher functional class than crossroad, it is coded as "high" priority. If it is on par with the crossroad, it was assumed to have "equal" priority. If it is a lower functional class than the crossroad, it was given "low" priority. The number of multiple upstream signals is coded to account for progression effect as a result of signal coordination.

The methodology employed in the upgraded ISTDM is to use the presence, priority, and synchronization of signal approaches coded in the network to adjust the free-flow speed and roadway capacity for signals. Congestion delay effects related to signals can therefore be treated using volume-delay functions similar to mid-block congestion delay. Although this method may not produce as accurate an estimation of delays at congested signals as other more complex methods, the method has worked very well for the purposes of modeling the effect of signal impedance on the assignment of traffic to signalized corridors in the context of an entire roadway network in a traditional demand models using an equilibrium assignment. The method has performed remarkably well resulting in very accurate roadway loadings even in fairly congested urban models, although some modest adjustment is often required in post-processing to improve speed calibration. (See also the discussion of signal delay in Section 1 of Chapter IX on POST_ALT.)

Although the HCM 2000 specifies (in Eq. 15-1) total delay at signals as the sum of three terms (uniform, incremental, and queue delay), because congestion effects (including incremental and queue delays) are modeled through the volume delay function, only the first term specifying the uniform delay is applied in this method. This first term, or the equation for uniform delay (HCM 2000 Eq. 15-2), adapted from the first term of Webster's delay formulation, can be further simplified for the consideration of free-flow conditions (in which case the v/c term approaches zero and ceases to be significant) to the form:

$$d = 0.5C\left(1 - \frac{g}{C}\right)^2 \cdot PF$$

where,

d = delay per vehicle,
g = effective green time,
C = cycle length, and
PF = progression adjustment factor.

Delay estimated from the above equation is then added to the link's free-flow travel-time to come up with an "adjusted" free-flow travel time for each direction of travel. Based on the fact that the mainline road is given a higher priority than the lower-class crossroad, varying green time ratios (g/C) were assumed by the priority code of the signal approach. HCM provides the progression adjustment factor as a function of the green time ratio and the arrival type. The arrival type for the signal approach was assumed based on the upstream signals coded in the network. With the assumed green time ratio and the arrival type, an appropriate progression factor in HCM was sought and used to estimate signal delay of the approach.

The capacity reduction methodology was based on travel-speed reductions resulting from delays on the flow-interrupted facilities. The service flow rate is a function of the travel time along a road segment. Increasing signal densities effectively reduces travel speeds, and, in turn, reduces the amount of traffic flow that is possible. The reduction in service flow was calculated by dividing a service flow estimate based on free-flow speed by a service flow estimate based on the "adjusted" free-flow speed based on traffic signal delay. The formula for the capacity reduction due to signals is therefore of the form:

$$f_s = \frac{a * \ln(FFS) - b}{a * \ln(AFFS) - b}$$

where,

f_s = capacity reduction factor for signal delay,
a, b = constants,
FFS = free-flow speed, and
AFFS = "adjusted" free-flow speed with signal delay.

These speed and capacity adjustments due to traffic signals were made directionally. Thus, signal approach lanes and the departing lanes in the other direction were estimated with different speed and capacity values. This models the reality that the delay and reduction of capacity occur on the upstream (arrival) side of signals and not the downstream (departing) side.

VIII. MODEL COMPONENTS

A. TRIP GENERATION

Trip generation models of the I-69 ISTDM consisted of trip production and trip attraction models developed by trip purpose. Four person and auto trip purposes were analyzed: home-based work, home-based other, non-home-based, and long purpose trips. Trip production models were estimated using cross-classification techniques, while trip attraction models were estimated using regression techniques. Trip production trip rates were linked to household size and auto ownership by zone. Trip attraction rates were specified as a function of employment by zone. Models were developed using the 1995 Indiana Household Survey dataset, which included only households within Indiana. Trip generation procedures for the long purpose trips were developed for Indiana-to-Indiana trips only. Long purpose trip tables external to Indiana were taken from the Corridor 18 Model dataset.

Updated features in trip generation of the upgraded ISTDM included the followings:

- Household stratification curves were adopted to adjust for changes in household size and auto ownership over time.
- Trip production and attraction models were refined to account for three area types: urban, suburban, and rural.
- Trip production and attraction models were developed for the long purpose trips to include internal zones in states other than Indiana.
- Trip attraction models were re-estimated to be consistent with the updated employment categories.
- Long purpose trip production models were linked to household income and vehicle availability.
- Household data (household size, income and vehicle availability) for the base year trip generation models were updated based on 2000 Census data.

1. <u>Data Inputs</u>

The data requirements for trip generation modeling are:

- Updated land use databases necessary to apply the trip generation models for the internal and external areas,
- Year 2000 household data including household size, income, and number of vehicles available for Indiana by TAZ, and
- Travel survey data regarding trip-making characteristics from existing sources including the 1995 Indiana Travel Survey and the 2001 NHTS.

2. Household Stratification Curves

In order to apply the cross-classified trip rates developed from the analysis of the household survey data, it is necessary to produce breakouts of the households within a TAZ into the categorical groupings used to breakout and define the trip rates. In the base year, this breakout is available from Census data, and in past versions of the statewide model, the same proportional breakouts have been assumed in the future year as in the base year. However, in the upgraded ISTDM, for future years, the breakout (cross-classification) is estimated by the application of curves (usually, piecewise functions created from linear, 2nd and 3rd degree polynomials) that stratify households among these categorical groupings (e.g., 0, 1, 2, 3+ autos-per-household) as a function of the zonal mean for that variable (e.g., 1.8 cars per household).

There are numerous advantages to this approach. This approach of utilizing stratification curves allows the trip generation model to use predictor variables that are not limited to those which can be obtained at the zonal level from the Census Transportation Planning Package (CTPP). It also allows for the disaggregation of TAZ defined for the CTTP as has been done for this version of the ISTDM, and perhaps most importantly, it makes this version of the model sensitive to forecasted changes in secondary predictor variables. If the number of autos-per-household is rising for the model area and this trend is forecasted to continue, then by raising the average autos-per-household in the TAZ for the future year (either allocating it specifically to TAZ with high income households and larger household sizes presumably where the additional autos would be accounted for, or even by simply scaling up the average across the whole region), the model can make a more accurate prediction of future traffic.

The coefficients of the household stratification curves were statistically specified directly from the base year Census data for the model area. The curves are incorporated into the trip generation program code and operate automatically whenever the program is run for forecast year conditions.

Within the trip generation model, the stratification curves are applied to the zonal data, and the trip production rate is applied to the resulting percentage of households at each level of the variable. The total production for the zone is the summation of the trips generated at each level.

Development of Stratification Curves

The primary data source for the calibration of stratification curves is the CTPP. Using the CTTP TAZ level data, the distribution of the households by size, auto ownership or workers is available. For each level of the variables defined (i.e. Household size = 1, 2, 3, 4+), SPSS was used develop a series of curves to estimate the percentage of households at that level based on the difference between the zonal average and the overall average. Linear, Quadratic, and Cubic curves were tested. The R-squared values were reported to determine which curve best fit the data.

Using the curves estimated by SPSS, a manual procedure was used to determine the best curve for each level of the variable when combined with the other levels. The chosen set of curves had to produce a reasonable distribution of households (percent) at each level of the variable throughout a range of zonal averages. This procedure ensures that when the curves are applied to the model zonal data, reasonable results are returned. **Table 4** reports the formulation of the selected curves.

These curves are applied with the trip generation model to the difference between the zonal average of the selected variable and the regional average to calculate the percentage of households at each level for purposes of calculating trip productions.

Table 4. Applied Stratification Curves

Dependent	Mth	Rsq	d.f.	F	Sigf	b0	b1	b2	b3
P_H1	LIN	0.326	4456	2159.99	0	0.2347	-0.1488	0	0
PHHP2	MAN	0.156	247	22.89	0	0.4235	-0.0089	-0.1192	0
P_H3	Cust	0.067	4454	106.15	0	0.275	0.0347	-0.053	0.0136
P_H4	LIN	0.362	4456	2528.97	0	0.2435	0.1361	0	0
P_V0	CUB	0.433	3974	1009.91	0	0.065	-0.1152	0.1541	-0.0722
P_V1	LIN	0.405	3976	2704.56	0	0.3066	-0.1999	0	0
P_V2	LIN	0.155	3976	729.18	0	0.3994	0.0958	0	0
P_V3	QUA	0.517	3975	2126.33	0	0.2122	0.2065	0.0254	0
P_I02	CUB	0.456	4436	1238.44	0	0.1721	-0.000006	1.1E-10	-5E-16
P_I24	LIN	0.262	4438	1574.63	0	0.2704	-0.000003	0	0
P_I46	CUB	0.087	4436	141.37	0	0.2431	6.5E-07	-7E-11	3.8E-16
P_I6	CUB	0.574	4436	1993.96	0	0.314	0.000008	-3E-11	-2E-17

Source: Bernardin, Lochmueller & Associates, Inc., 2004.

Figures 6 through **8** provides a graphical representation of the stratification curves applied to a range of average values for the variable. At each value of the average, the disaggregation of the number of households into each level will equal the zonal total.

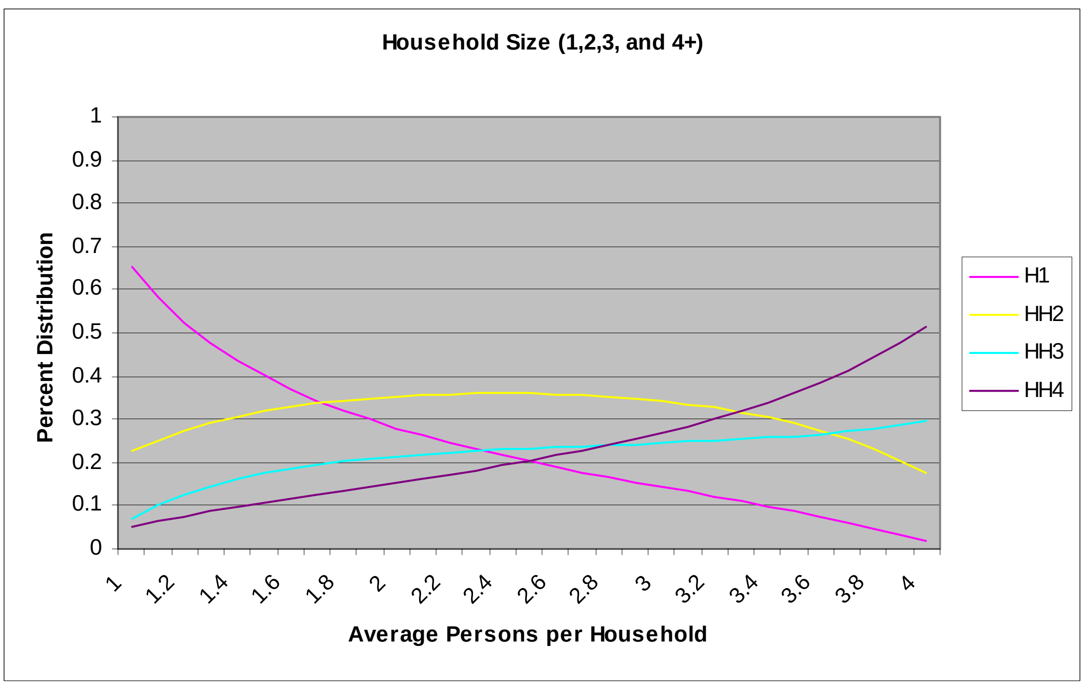


Figure 6. Household Size Stratification Curves
(**Source**: Bernardin, Lochmueller & Associates, Inc., 2004)

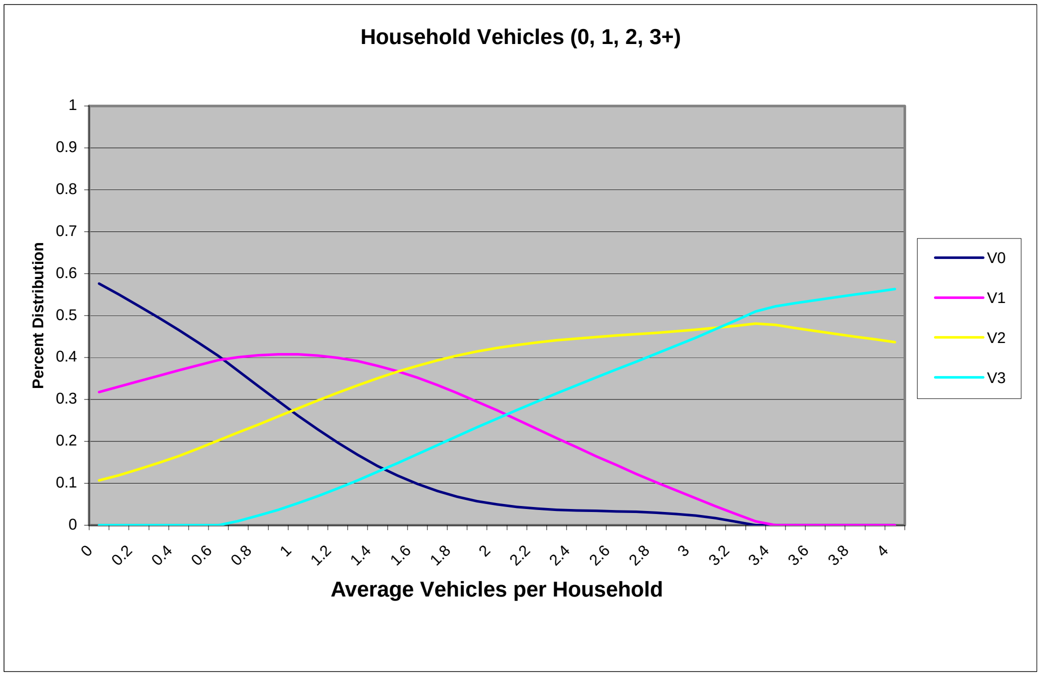


Figure 7. Household Vehicles Stratification Curves
(**Source**: Bernardin, Lochmueller & Associates, Inc., 2004)

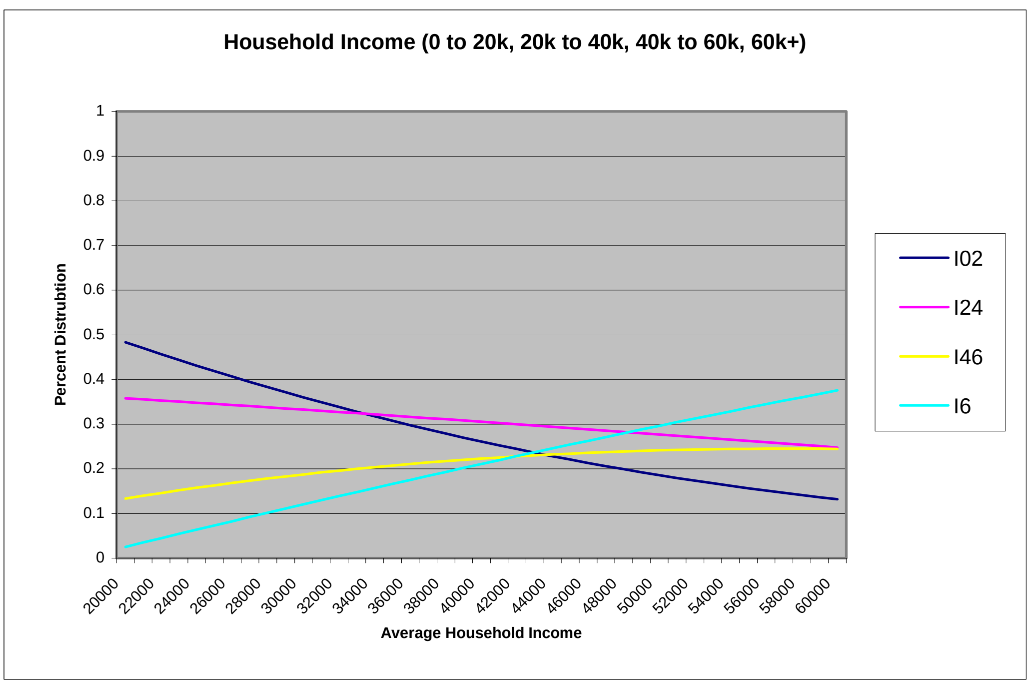


Figure 8. Household Income Stratification Curves
(**Source**: Bernardin, Lochmueller & Associates, Inc., 2004)

3. Trip Production Model

Trip production rates were initially developed based on observed data from the 1995 Indiana Travel Survey and the 2001 NHTS and subsequently adjusted based on outside sources including *NCHRP Report 365: Travel Estimation Techniques for Urban Planning*. **Tables 5** through **8** show the final validated trip production rates by area type which are cross-classified by household size and/or income category and auto ownership for each trip purpose.

Table 5. Validated Trip Production Rates: Home-Based Work Trip Purpose (Average Weekday Trips per Household)

Area Type	Household Size	Vehicles Available			
		0	**1**	**2**	**3+**
Urban	1	0.564	1.127	1.127	1.127
	2	1.235	1.678	2.147	2.147
	3	1.571	1.786	2.752	3.396
	4+	2.027	2.120	3.101	3.785
Suburban	1	0.513	1.015	1.015	1.015
	2	1.118	1.518	1.939	1.939
	3	1.426	1.621	2.492	3.077
	4+	1.826	1.918	2.810	3.426
Rural	1	0.574	1.149	1.149	1.149
	2	1.262	1.703	2.185	2.185
	3	1.600	1.826	2.800	3.457
	4+	2.062	2.154	3.159	3.857

Source: Cambridge Systematics, Inc., 2004.

Table 6. Validated Trip Production Rates: Home-Based Other Trip Purpose (Average Weekday Trips per Household)

Area Type	Household Size	Vehicles Available			
		0	**1**	**2**	**3+**
Urban	1	1.264	2.404	2.404	2.404
	2	2.945	4.863	5.235	5.235
	3	4.874	6.838	6.973	7.424
	4+	7.797	9.297	11.158	12.377
Suburban	1	1.077	2.051	2.051	2.051
	2	2.513	4.154	4.462	4.462
	3	4.164	5.836	5.959	6.339
	4+	6.657	7.939	9.529	10.565
Rural	1	1.036	1.969	1.969	1.969
	2	2.421	3.980	4.287	4.287
	3	3.990	5.600	5.713	6.082
	4+	6.390	7.621	9.149	10.134

Source: Cambridge Systematics, Inc., 2004.

Table 7. Validated Trip Production Rates: Non-Home Based Trip Purpose (Average Weekday Trips per Household)

Area Type	Household Size	Vehicles Available			
		0	1	2	3+
Urban	1	0.676	1.625	1.625	1.625
	2	1.151	2.335	2.561	2.561
	3	1.828	2.730	2.923	3.633
	4+	2.121	3.803	4.942	5.033
Suburban	1	0.923	2.226	2.226	2.226
	2	1.580	3.190	3.508	3.508
	3	2.503	3.744	4.000	4.964
	4+	2.892	5.200	6.759	6.893
Rural	1	0.656	1.600	1.600	1.600
	2	1.139	2.287	2.523	2.523
	3	1.795	2.687	2.872	3.569
	4+	2.082	3.734	4.852	4.944

Source: Cambridge Systematics, Inc., 2004.

Table 8. Validated Trip Production Rates: Long Trip Purpose (Average Weekday Trips per Household)

Income Category	Vehicles Available			
	0	1	2	3+
$0 to $20k	0.0099	0.0300	0.0579	0.0595
$20k to $40k	0.0199	0.0599	0.1157	0.1188
$40k to $60k	0.0245	0.0737	0.1424	0.1461
$60k +	0.0377	0.1136	0.2195	0.2252

Source: Cambridge Systematics, Inc., 2004.

4. Trip Attraction Model

Trip attraction rates were re-estimated using the updated land use data including new employment categories with observed data from the 1995 Indiana Household survey. **Table 9** shows the final regression parameters for the validated attraction models. As is often the case, the explanatory power of the purpose specific attraction models was not as high as one would like, with adjusted R-squared measures of between about 0.15 and 0.60. However, because the model coefficients appear to have reasonable signs and because the overall attractions were balanced to the number of estimated trip productions, the models were deemed acceptable.

Table 9. Regression Models for Trip Attractions by Trip Purpose

Trip Purpose	Variable	Parameter Estimate
Home-Based Work Trips	Intercept	0.000
	Employment in Retail, FIRE, Education, Services, and Government Sectors	1.400
	Employment in Non-Retail; Construction; Manufacturing; Agriculture, Forestry and Fisheries; and Transportation Sectors	1.120
Home-Based Other Trips	Intercept	0.000
	Employment in Retail Sector	4.850
	Employment in FIRE, Education, Services, and Retail Sectors	3.200
	Employment in Education Sector	1.750
	Households	1.650
Non-Home-Based Trips	Intercept	0.000
	Employment in Retail Sector	4.490
	Employment in FIRE, Education, Services, and Government Sectors	1.130
	Employment in Non-Retail, Construction, Manufacturing, and Transportation Sectors	0.380
	Households	0.590
Long Trips	Intercept	0.000
	Total Employment	0.023
	Employment in FIRE, Education, Services, and Government Sectors	0.090
	Employment in Agriculture, Forestry and Fisheries; Mining; Construction; Manufacturing; Non-Retail; and FIRE Sectors	0.030
	Employment in Retail and Services Sectors	0.020

Source: Cambridge Systematics, 2004.

5. Trip Generation Results

The final rates were then applied to the updated socioeconomic data to produce total Indiana trip productions by trip purpose. Regional trip making statistics were compared to national averages reported in FHWA's *Model Validation and Reasonableness Checking Manual*. The results are displayed in **Table 10**.

Table 10. Estimated Indiana Trip Productions by Purpose (2000 Base Year Average Weekday Trips)

Trip Purpose	Trips	Trips/HH	Trips/Person
Home-Based Work Trips	5,019,285	2.148	0.826
Home-Based Other Trips	13,102,906	5.608	2.155
Non-Home-Based Trips	6,755,622	2.892	1.111
Long Trips	280,395	0.120	0.046
Indiana Total	**25,158,208**	**10.768**	**4.138**
Validation Targets*	**N/A**	**8.0 to 12.0**	**3.5 to 4.0**

***** Based on FHWA's Model Validation and Reasonableness Checking Manual
Source: Cambridge Systematics, 2004.

6. Trip Balancing

The next step of trip generation modeling was to factor the number of trips by purpose predicted by the trip attraction model to be consistent with the number of trips predicted to be produced by the production models. The total number of study area trip attractions was balanced to equal total productions. In addition, the number of trips being produced and attracted in each of the major areas external to Indiana subareas or super districts were balanced. This latter step was required to account for major imbalances in productions and attractions in the larger external metropolitan area TAZ's near Indiana's border. The most notable of the imbalances were trips produced and attracted in the Chicago area. Without balancing, these larger TAZ's created large attractors close to the border resulting in unrealistic travel across state lines.

B. TRIP DISTRIBUTION

The statewide model uses the gravity model approach for trip distribution. Data from the 1995 Indiana Household Survey and the 2001 NHTS was used to obtain the trip length distributions by purpose and travel time for gravity model calibration.

Gravity models incorporated the following improvements to the I-69 ISTDM:

- A single feedback of congested times to the gravity model was implemented. A feedback involves an initial trip distribution step performed on the free-flow speeds contained within the transportation network. Outputs from this step are then used to estimate a daily trip table that is assigned to the network to produce estimated congested link speeds. These congested speeds are then used as inputs into the gravity models to estimate the final person trip tables.

- New friction factor curves were calibrated to address the refined transportation network and smaller zone sizes within Indiana.

- Gravity models for the long trip purpose were developed to distribute trips between all study area internal TAZ's including areas external to Indiana.

1. Data Inputs

The data requirements for trip distribution modeling include:

- Updated transportation networks and zone systems for the entire modeling area containing necessary information for trip distribution applications. Primarily, this data includes the link impedance values identified on the transportation network.

- Travel survey data regarding trip-making characteristics including trip length and trip origin/destination patterns from existing sources (1995 Indiana Travel Survey and 2001 NHTS).

2. Friction Factors

The friction factor in the Gravity model is a key component that represents the magnitude of frictions (or impedances) in traffic flows between pairs of TAZs. Friction factors were derived/calibrated by trip purpose to fit with more refined zonal systems in the upgraded ISTDM. The factors were calibrated to observed travel times obtained from the 1995 Indiana Travel Survey and supplemented with information from the 2001 NHTS. These factors were subsequently smoothed to reduce errors not shown from the data.

Figure 9 presents friction factors for home-based work, home-based other and non-home-based trips which are expressed by trip length in minutes. Friction factors for long trips use distance instead of time for trip length since long trip distribution is more dependent on distance than time. **Figure 10** shows a friction factor curve for long trips.

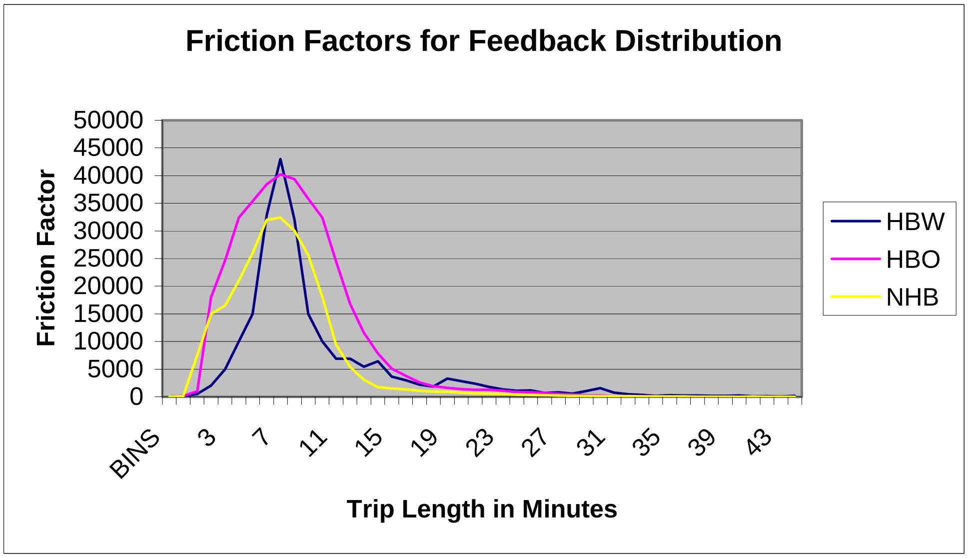


Figure 9. Friction Factors for HBW, HBO and NHB Trips
(**Source**: Cambridge Systematics, 2004)

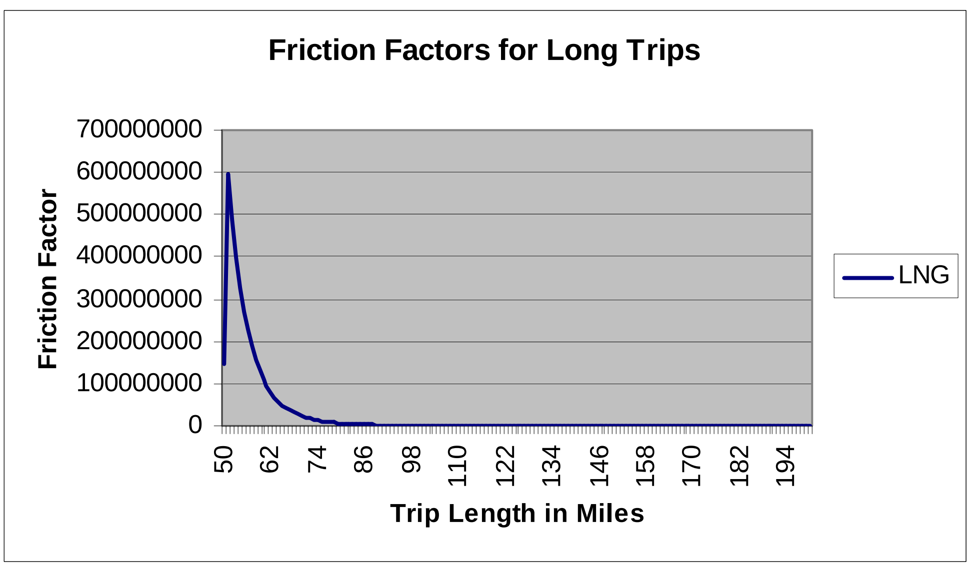


Figure 10. Friction Factors for Long Trips
(**Source**: Bernardin, Lochmueller & Associates, Inc., 2004)

3. Socioeconomic Adjustment Factors

Socioeconomic adjustment factors or K-factors were used in trip distribution calculations to adjust origin and destination trip interchanges not replicated very well in the gravity modeling process. K-factors are often used where bridges, other perceived travel barriers, or special socioeconomic factors (such as housing prices) may distort the distribution of trips between specific areas in a given modeling area.

Zone-to-zone adjustments for selected interchanges using K-factors were mainly made in a super zone level. These trip distribution refinements for the upgraded ISTDM were necessary to better represent trip distribution between areas of the study area and to validate trip movements across state boundaries. **Figure 11** shows final validated average K-factors by TAZ.

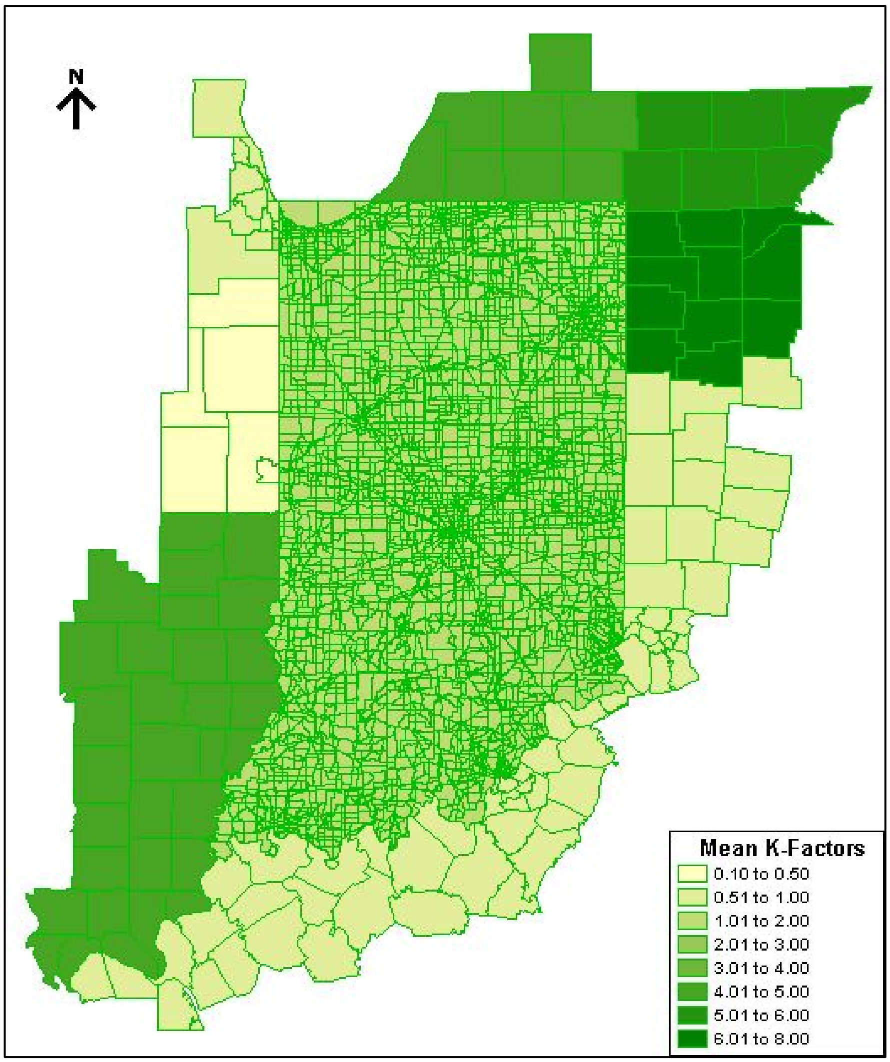


Figure 11. Average K-Factors by TAZ
(**Source**: Bernardin, Lochmueller & Associates, Inc., 2004)

4. Trip Distribution Outputs and Results

The calibrated friction factors and K-factors were input, along with the trip productions and attractions and travel times and distances, into the gravity model application runs for each trip purpose. This step resulted in the development of production and attraction trip matrices in TransCAD format.

Table 11 compares the resulting trip lengths to observed trip lengths by purpose for the final, congested gravity models. The person trip tables generated from this process were inputs into the mode choice step.

Table 11. Average Trip Lengths by Purpose: Observed versus Estimated

Trip Purpose	Observed Average Travel Time (min)	Estimated Average Travel Time (min)	% Difference Target +/- 5%
Home-Based Work	20.11	20.15	0.2%
Home-Based Other	14.56	14.53	-0.2%
Non-Home-Based	14.41	14.82	2.8%
Long	127.70	121.93	-4.5%

Source: Cambridge Systematics, Inc. 2004.

C. MODE CHOICE MODEL

Mode choice procedures were updated to meet the needs of the refined study area transportation network and TAZ layer and to include some sensitivity to the differences in mode choices related to area type.

Updated features included:

- Mode shares for HBW, HBO, and NHB trip purposes were reviewed and updated to account for area type based on the 1995 Indiana Travel Survey and/or 2001 NHTS data.
- The multinomial logit model for the long trip purpose was re-validated to account for changes in the travel model network and TAZ layers.
- TransCAD's transit network functions were automated and included in the model GIS-DK script.

1. Mode Share Results – HBW, HBO & NHB

Information from the 1995 household survey was used to develop mode shares for the three shorter trip purposes classified by area type. Auto shares were then applied to the trip table outputs from the trip distribution models to create auto person trip tables for the HBW, HBO and NHB trip purposes. **Table 12** shows the observed mode shares developed from the survey data. The auto share factors that appear in this table are applied to the total person trips for the HBW, HBO and NHB trip purposes that are generated in the trip distribution step to create auto person trip tables. Auto occupancy factors are then applied to the auto person trips to create auto vehicle trip tables. The auto occupancy factors developed for the I-69 ISTDM were based on the 1995 Indiana Household Survey and were not changed for this update. The surveyed auto occupancies by trip purpose used in this modeling process were:

- Home-based work trip purpose – overall auto occupancy was 1.20,
- Home-based other trip purpose – overall auto occupancy was 2.15,
- Non-home-based trip purpose – overall auto occupancy was 1.87,
- Long trip purpose – overall auto occupancy was 3.06.

Table 12. Observed Mode Shares by Area Type and Trip Purpose

Trip Purpose	Mode	Urban	Suburban	Rural
HBW	**Auto**	**93.8%**	**99.7%**	**98.1%**
	Bus	1.4%	0.0%	0.0%
	Walk	1.2%	0.3%	1.9%
	Bike	3.6%	0.0%	0.0%
HBO	**Auto**	**80.3%**	**80.9%**	**77.4%**
	Bus	1.3%	0.2%	0.0%
	School Bus	8.8%	15.7%	16.8%
	Walk	7.4%	2.8%	4.8%
	Bike	2.2%	0.5%	1.0%
NHB	**Auto**	**97.7%**	**97.4%**	**97.0%**
	Walk	2.2%	2.6%	3.4%
	Bike	0.1%	0.0%	0.1%

Source: Cambridge Systematics, Inc. 2004.

2. Mode Choice Results – Long Trips

Observed mode share data for intercity trips was obtained from the 1995 Indiana household travel survey. This information was used along with updated level of service data from the refined network to calibrate the base year model parameters. **Table 13** shows the various cost and travel time matrices that were used as inputs into the multinomial logit model for the long trip purpose of the upgraded ISTDM. **Table 14** shows the initial constants and coefficients transferred from the California High Speed Rail Study Model and the final bias constant applied during the re-calibration of the upgraded ISTDM. Finally, **Table 15** shows the results of the applied logit model with the updated inputs for the ISTDM. This analysis was limited to service areas near inter-city transit routes which are shown in **Figure 12**.

Table 13. Updated Indiana Model Base Year Impedance Matrices

Matrix File	Component Matrix	Contents
TIMES.MTX	FFLOW	Skim of free flow highway travel time
	IVTT	Skim of free flow highway travel time between stations
	OVTT	Skim of highway free flow travel time between TAZ's and transit nodes
COST.MTX	AUTO	Skim of distance * $0.15
	TRANSIT	Skim of distance * $0.21

Source: Cambridge Systematics, Inc., November 2000.

Table 14. Re-validated Multinomial Logit Model Parameters – Long Trip Purpose

Variable	Original Values	Adjusted Values
Cost ($)	-0.0276	-0.0276
IVTT - Line Haul Travel Time (min)	-0.0069	-0.0069
OVTT - Access/Egress Time (min)	-0.0083	-0.0083
Bias Constant	-0.87	-1.15

Source: Cambridge Systematics, Inc. 2004.

Table 15. Estimated Daily Transit Trips – Long Trip Purpose

Interchange	Transit Trips	Person Trips	Percent Transit	Target
Indiana to Indiana	14,841	159,541	9.3%	9.4%
Indiana to External Area	7,255	123,195	5.9%	N/A
External Area to Indiana	6,800	120,853	5.6%	N/A
Total Indiana	**28,896**	**403,589**	**7.2%**	**N/A**

Source: Cambridge Systematics, Inc. 2004.

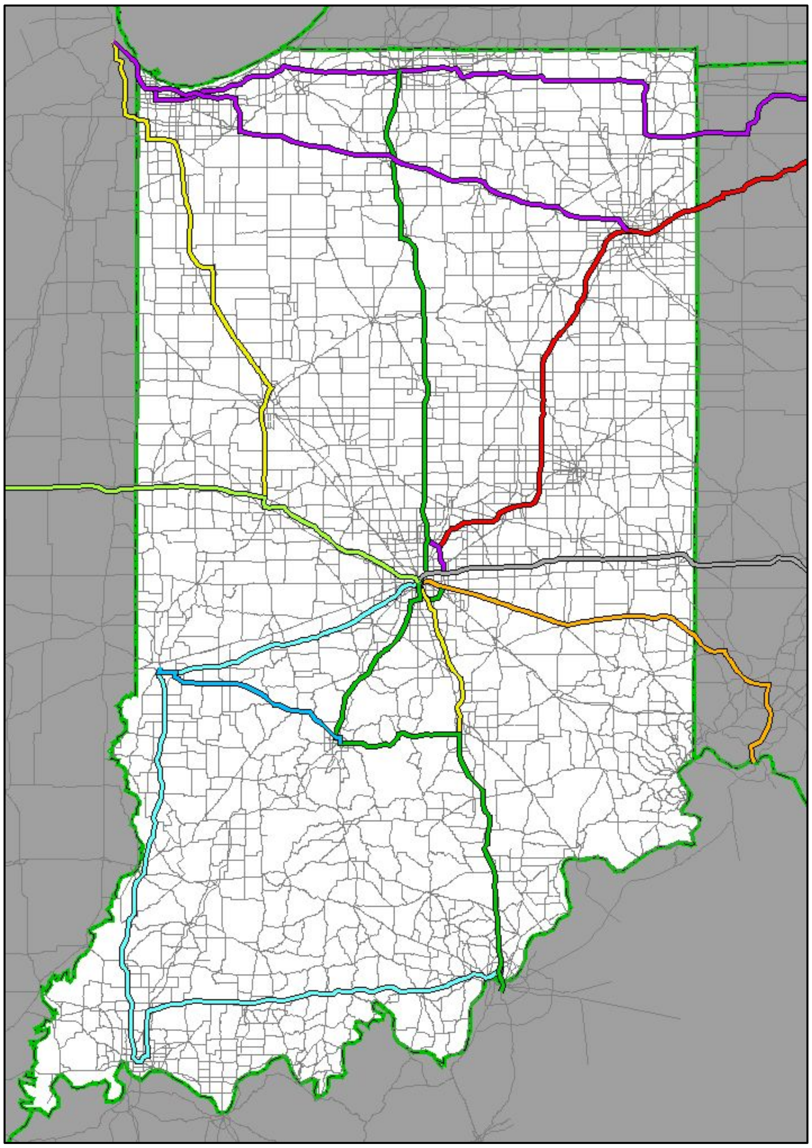


Figure 12. Transit Routes
(**Source**: Cambridge Systematics, Inc. 2004)

D. EXTERNAL MODELS AND CUMULATIVE DEMAND

In the I-69 and upgraded ISTDM, external stations were coded into the transportation network outside of the detailed, expanded external modeling areas in eastern Illinois, western Kentucky, southern Michigan, and western Ohio. These external stations were structured to identify the potential cumulative travel demand generated by the multi-state alternatives of the Corridor 18 Transportation Study. External station-to-external station and external station-to-internal zone trip tables from the Corridor 18 Transportation Study were formatted and refined to be consistent with the updated network and zone layers. In addition, these revised trip tables were factored up to year 2000 base and year 2030 future levels based on existing and estimated auto and truck traffic flows from FHWA's Freight Analysis Framework (FAF) program. Because of the large regional influence on travel patterns related to the proposed I-69 Indianapolis to Evansville project, two separate sets of external trip tables were developed for the 2015 and 2030 future year conditions to reflect the study area with and without this project.

E. TRUCK MODELS

Truck trip table development procedures were modified from the I-69 model in order to provide more sensitivity to changes in land use as well as to incorporate the effects of changes in worker productivity over time. The I-69 ISTDM used Origin-Destination-Matrix-Estimation (ODME) procedures to create truck trip tables for all types of trucks. This method introduces limitations on the sensitivity of the truck trip tables to changes in Indiana's future population and employment centers by imposing a fixed trip pattern or distribution to the base and future year truck trips. Consequently, more dynamic methods of truck trip table development were developed for the upgraded ISTDM.

Updated features are summarized as follows:

- Base and future year commodity flow truck tables from a research project conducted by Dr. William R. Black at Indiana University entitled *Transport Flows in the State of Indiana: Commodity Database Development and Traffic Assignment Phases I & II* served as the basis for the freight truck trip tables. The following steps were undertaken to produce truck trip tables representing the freight component:

    1. Base year 1993 truck trip tables from the Indiana University study were factored up to year 2000 levels by commodity group.

    2. Future year growth factors were applied by commodity group to develop future year trips. Growth factors were developed by estimating base and future year freight truck trip ends on a zonal basis. Freight truck trip ends were estimated by applying trip generation equations from FHWA's *Quick Response Freight Manual* to base and future year land use on a zonal basis. Future year trip ends were then adjusted further by applying an additional growth factor related to changes in productivity as estimated by the Indiana version of the REMI model.

- Non-freight truck trip tables were estimated using ODME procedures. This involved:

    1. Target volumes for the base year trip tables were developed by subtracting the assigned freight trucks from the total truck counts at selected locations. These targets were used as inputs into the ODME process to produce base year non-freight truck trip tables.

2. Future year non-freight truck trips were estimated by applying growth factors to the base year non-freight trucks. Non-freight growth factors were estimated by applying trip generation equations from FHWA's Quick Response Freight Manual to base and future year land use on a zonal basis.

1. Data Inputs

The data requirements for truck modeling include:

- Truck classification counts collected from automatic traffic recorders deployed throughout Indiana.
- Forecasts of changes in productivity by commodity type (10 groups) from the Indiana REMI model, (see **Table 16**).
- Quick Response Freight Manual trip generation equations, (see **Table 17**)
- Base and future year land use by TAZ.
- Base year commodity flow truck trip tables.

Table 16. Estimated Changes in Worker Productivity (Indiana Version of REMI Model)

Employment Category	Productivity Factors (2000-2030)
Durables Manufacturing	2.92
Non-Durables Manufacturing	1.79
Mining	2.64
Construction	1.60
Transportation & Public Utilities	1.96
FIRE	1.91
Retail Trade	1.67
Wholesale Trade	2.71
Services	1.33
Agriculture, Forestry & Fisheries	0.78

Source: Cambridge Systematics, Inc. 2004.

Table 17. Truck Trip Generation Rates – Quick Response Freight Manual (Average Weekday Truck Trips per Employee)

Employment Category	Four-Tire Vehicles	Single Unit Trucks (6+ Tires)	Combination Trucks	Total
Agriculture, Mining and Construction	1.110	0.289	0.174	1.573
Manufacturing, Transportation, Communications, Utilities and Wholesale Trade	0.938	0.242	0.104	1.284
Retail Trade	0.888	0.253	0.065	1.206
Office and Services	0.437	0.068	0.009	0.514
Households	0.251	0.099	0.038	0.388

Source: Cambridge Systematics, Inc. 2004.

2. Truck Estimation Results

Table 18 shows the assignment results of the ODME process for the non-freight portion of the truck assignments for the base year. **Table 19** shows the overall (freight and non-freight) truck assignment results for the base year.

Table 18. Non-Freight Truck ODME Assignment Results

Roadway Type	FHWA Func. Class	Number of Observations	Mean Count	Mean Assigned Volume	Mean Volume Deviation	Percent Volume Deviation	Percent RMSE	Mean VMT Deviation
Rural Interstate	1	87	3,598	3,560	-38	-1.1%	10.6%	0.2%
Rural Principal Arterial	2	176	1,076	1,074	-2	-0.2%	3.4%	-0.3%
Rural Minor Arterial	6	202	500	500	0	0.0%	4.3%	-0.5%
Rural Major Collector	7	458	206	204	-2	-0.7%	12.4%	-0.5%
Urban Interstate	11	58	6,141	6,127	-14	-0.2%	3.8%	-0.4%
Urban Principal Arterial	12	18	3,514	3,506	-8	-0.2%	4.4%	-0.3%
Urban Minor Arterial	14	57	1,064	1,059	-5	-0.4%	3.1%	-0.7%
Urban Major Collector	16	15	1,439	1,436	-3	-0.4%	0.6%	-0.2%
Total		1,071	549	547	-2	-0.4%	11.2%	-0.1%

Source: Cambridge Systematics, Inc. 2004.

Table 19. Total Truck Assignment Results

Roadway Type	FHWA Func. Class	Number of Observations	Mean Count	Mean Assigned Volume	Mean Volume Deviation	Percent Volume Deviation	Percent RMSE	Mean VMT Deviation
Rural Interstate	1	171	8,584	8,303	-280	-3.27%	25.29%	-5.89%
Rural Principal Arterial	2	502	2,173	1,927	-246	-11.32%	31.46%	-13.77%
Rural Minor Arterial	6	173	1,576	1,420	-156	-9.93%	42.44%	-13.12%
Rural Major Collector	7	47	1,639	919	-719	43.90%	98.59%	-33.48%
Urban Interstate	11	118	10,590	10,246	-343	-3.24%	39.81%	-4.35%
Urban Principal Arterial	12	50	3,228	3,077	-151	-4.69%	34.67%	-7.09%
Urban Minor Arterial	14	132	2,352	1,983	-368	-15.68%	94.76%	-9.29%
Urban Major Collector	16	7	6,681	1,091	-5589	-83.67%	146.28%	-77.03%
Total		1,200	3,897	1,100	-306	-7.88%	51.40%	-7.29%

Source: Bernardin, Lochmueller & Associates, Inc., 2004.

F. TRIP ASSIGNMENT MODELS AND CALIBRATION/VALIDATION

Assignment procedures of the I-69 ISTDM involved free-flow based time-of-day modeling with truck trips were assigned before auto trips. Then, truck volumes on links were used as pre-loads prior to auto assignment.

The upgraded ISTDM employed the following updates to the assignment procedures:

- Simultaneous multi-modal multi-class assignment (MMA) method was adopted instead of the assignment based on "pre-load". In this method, trucks are loaded to the network as the same time as auto trips. In this way, truck assignment does not depend on free-flow conditions, but is subject to congestion-based diversion. With the MMA method, truck loadings are more realistic especially for testing bypasses versus through-town upgrades.

- Truck trips were assigned in two classes: freight truck and non-freight truck trip tables. While the difference in these classes does not directly correspond to a vehicle type distinction, it is meaningful in terms of vehicle weights (and associated wear on pavement) and potentially also in value of time for economic analyses.

- A feedback loop was incorporated so that the assignment process is run twice. Following the first assignment which is based on free-flow conditions, daily congested time is calculated and the link congestion is used to redistribute trips in the gravity model in the second round of the assignment process.

- Time-of-day procedures were removed. This design change greatly reduced the model's run time, offsetting much of the increase due to additional zones. It also addressed possible issues regarding the independent validity of the time-of-day period assignments which could not independently validated due to lack of detailed count data in electronic form.

- Multiple volume-delay functions were specified by functional classification on the basis of extensive experimentation with the functions made during model validation. Due to the method of capacity estimation adopted for the model which specifies an absolute capacity rather than a practical capacity, the ISTDM uses some different volume delay parameters than other models which use practical capacities. The default sets of volume-delay parameters for the Indiana statewide model are presented in **Figure 13**. Various parameters were tested and the final parameters arrived at through the process of validation of the assignment.

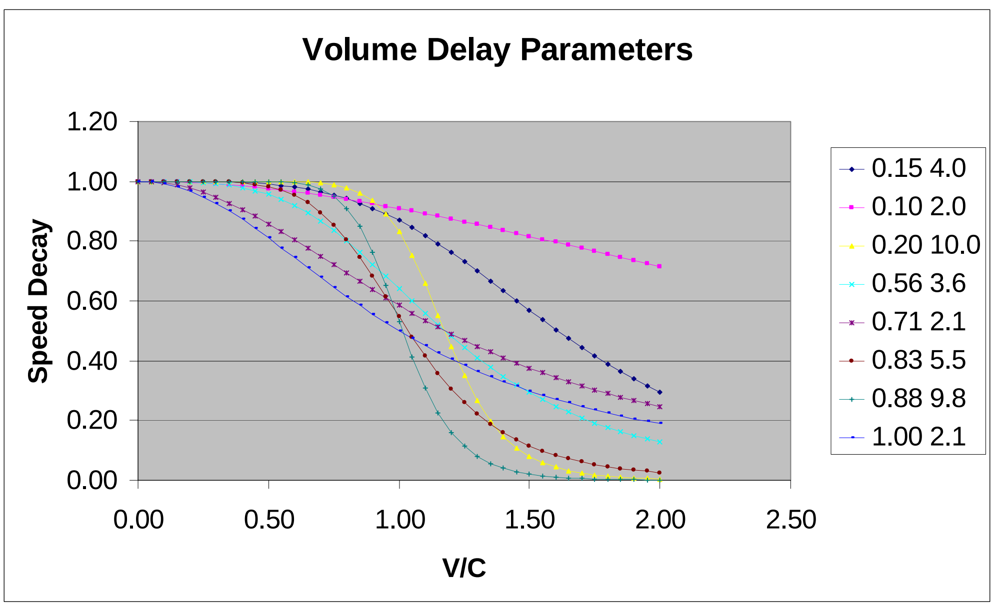


Figure 13. Volume-Delay Functions
(**Source**: Bernardin, Lochmueller & Associates, Inc., 2004)

1. <u>Data Inputs</u>

The data inputs used in trip assignment and validation process included:

- Daily origin-destination vehicle trip tables: Outputs from the trip distribution and subsequent matrix manipulation procedures.

- Highway network: The ISTDM highway network with key link attributes such as link free-flow travel times, link daily capacities, and volume-delay functions by functional classification.

2. Trip Assignment Validation

The base year ISTDM was validated by comparing the differences between observed daily traffic counts and assigned model daily volumes on the network links. System-wide validation statistics were broken out by roadway functional classification, volume-group range, screenline, major corridors, and area type.

The calibration and validation tasks began with the development of a special calibration report program, which is referred to as "CAL_REP". CAL_REP was originally developed by Bernardin, Lochmueller & Associates, Inc. as part of the Indiana Reference Modeling System (IRMS) for the purpose of quantifying model errors and assisting in the diagnosis of assignment problems. For the upgraded ISTDM, a new version of CAL_REP was customized in GIS-DK script to best fit to the model and the program was then embedded as a post-processing module in the user model interface for easy access and implementation. The features of the model interface and the post-processing module are given in the "Technical Memorandum: Model Users Guide".

Error statistics reported and used for diagnosing the possible sources of model errors include:

- percent root mean square errors (% RMSE),
- systemwide average error,
- mean loading errors and percentage errors, and
- total VMT errors and percentage errors.

The % RMSE is the traditional and single best overall error statistic used for comparing loadings to counts. It has the following mathematical formulation:

$$\%\mathrm{RMSE} = \frac{\sqrt{\sum(\mathrm{Count} - \mathrm{Loading})^2 / n}}{\mathrm{Mean\ Count}} \times 100$$

A model is in a high degree of accuracy when the systemwide % RMSE of the network gets down in the range of 30%. When evaluating % RMSE for groups of links disaggregated by volume ranges, relatively large errors are acceptable for low volume groups. But, the errors should become smaller as volume increases, in part due the decreasing percentage error in the counts themselves as volumes increase.

The overall validation tasks were based on following a decision-tree that begins with finding "global" problems in the model. This initial approach to correct global problems then moved on to the "sub-area" errors, and was completed by focusing on specific link problems. In these approaches, all roadways in Indiana in the model network with daily counts higher than 1,000 vehicles were targeted.

The global problems were first identified by a systemwide average error and a systemwide vehicle miles traveled (VMT) error. All model components affecting these problems were revisited and corrected where necessary. These efforts included:

- Modification to trip generation rates,
- Adjustment of friction factors,
- Adjustment of volume-delay functions,
- Adjustment of K-factors, and
- Modification to external trips.

The sub-area and individual link problems were then identified and applied with the following major corrections:

- Modification to centroid connectors,
- Adjustment of toll impedances,
- Adjustment of volume-delay functions, and
- Adjustment of K-factors.

Major corridors in the state that required special attention were identified and the link-level validation was focused on these facilities. These corridors, as shown in **Figure 14**, include all Interstates and major US highways and state routes.

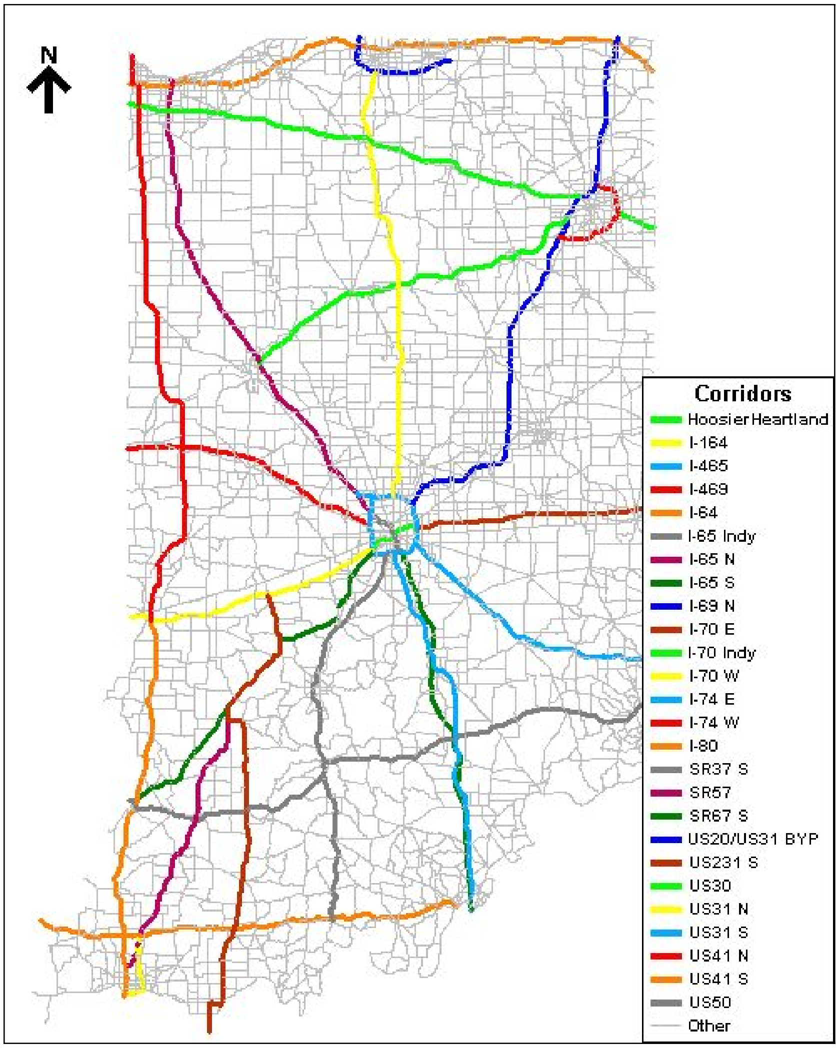


Figure 14. Major Corridors Identified for Validation
(**Source**: Bernardin, Lochmueller & Associates, Inc., 2004)

In this detailed level of validation, daily counts coded in the network were reviewed especially for the links that show higher discrepancy between the counts and loaded volumes. The model network includes several fields that contain daily counts. Main problems associated with the counts include:

- Variations in counts between crossroads,
- Identical counts after crossing crossroad,
- Identical mainline and ramp counts on the same roadway, and
- Variations in counts coded in the network for the same link.

To alleviate the above problems related to the counts, two special GIS-DK programs were written (1) to remove count coding errors associated with crossroad and (2) to pick the best count that agrees with assignment. After running these programs, manual judgmental adjustments were made where necessary based on the review of the output of these two programs and the review of any inconsistencies in coding.

3. <u>Traffic Assignment Validation Outputs</u>

The validation outputs from the base ISTDM were prepared in two levels. First, assignment/validation statistics for all Indiana roads including non-state jurisdictional highways were calculated to view overall validity of the model. Then, separate statistics were computed only for state jurisdictional highways to visualize the performance of state highways.

a. All Roads

Table 20 summarizes the errors by volume-group for all Indiana roads including local jurisdictional roads. In this table, "% Error" represents the percentage difference between ground counts ("Count Avg.") and model estimates ("Loading Avg."). Likewise, "VMT % Error" indicates the percentage difference in VMTs between counts and loadings.

On the whole, the model shows –1.26% loading error and 0.45% VMT error. The systemwide % RMSE is at 39.45%. As indicated in this table, as volume increases, smaller % RMSE and % errors are observed. Considering that these statistics include county roads and local streets, the model demonstrates its accurately calibrated/validated status.

The model's accuracy can be also verified in **Table 21**, which shows error reports by functional classification. High class roads such as Interstates, Freeways and Arterials show much smaller errors than those of lower class roads.

Table 20. Model Performance by Volume Group (All Roads)

CLASS	Count Avg.	Loading Avg.	% Error	VMT % Error	% RMSE
1,001 to 2,000 AADT	1,468	1,994	35.81	35.70	99.06
2,001 to 3,000 AADT	2,497	3,041	21.77	22.72	77.79
3,001 to 4,000 AADT	3,546	3,779	6.56	7.63	49.28
4,001 to 5,000 AADT	4,483	4,599	2.60	3.16	42.29
5,001 to 6,000 AADT	5,485	5,562	1.41	0.22	42.97
6,001 to 8,000 AADT	6,985	6,666	-4.58	-2.67	37.52
8,001 to 10,000 AADT	8,942	8,347	-6.66	-4.00	35.52
10,001 to 15,000 AADT	12,347	11,351	-8.06	-6.99	35.60
15,001 to 20,000 AADT	17,367	16,319	-6.04	-4.69	31.33
20,001 to 25,000 AADT	22,394	21,788	-2.71	-4.65	29.34
25,001 to 30,000 AADT	27,429	26,553	-3.19	-4.53	26.45
30,001 to 40,000 AADT	34,067	33,879	-0.55	1.85	21.93
40,001 to 50,000 AADT	44,086	44,801	1.62	-1.14	15.74
50,001 to 75,000 AADT	58,410	58,321	-0.15	0.79	13.22
75,001 to 100,000 AADT	86,069	89,403	3.87	4.23	14.60
> 100,000 AADT	119,874	115,256	-3.85	-1.77	19.87
All	**10,199**	**10,070**	**-1.26**	**0.45**	**39.45**

Source: Bernardin, Lochmueller & Associates, Inc., 2004.

Table 21. Model Performance by Functional Classification (All Roads)

CLASS	Counts Avg.	Loading Avg.	% Error	VMT % Error	% RMSE
Rural Interstates (1)	28,670	28,145	-1.83	-2.86	11.03
Rural Prin. Arterials (2)	9,147	9,027	-1.31	-0.20	24.86
Rural Minor Arterials (6)	6,499	6,666	2.57	4.33	34.74
Rural Major Collectors (7)	3,481	3,680	5.72	8.53	58.18
Rural Minor Collectors (8)	4,840	5,978	23.52	19.78	73.89
Rural Local Roads (9)	3,878	4,497	15.96	-11.01	77.26
Urban Interstates (11)	62,992	64,502	2.40	1.88	12.55
Urban Freeways (12)	23,146	23,460	1.36	1.10	25.86
Urban Prin. Arterials (14)	18,602	17,731	-4.68	-4.65	31.16
Urban Minor Arterials (16)	11,256	10,530	-6.45	-5.43	62.36
Urban Collectors (17)	7,953	7,995	0.53	-6.75	64.66
Urban Local Roads (19)	7,164	6,407	-10.56	-15.09	23.66
All	**10,199**	**10,070**	**-1.26**	**0.45**	**39.45**

Source: Bernardin, Lochmueller & Associates, Inc., 2004.

Individual corridors identified in **Figure 4** show high coincidence between counts and loadings. As indicated in **Table 22**, all corridors but one are within +/- 10% loading and VMT errors. % RMSE is less than 30% for all corridors but one.

Table 22. Model Performance for Major Corridors (All Roads)

CLASS	Counts Avg.	Loading Avg.	% Error	VMT % Error	% RMSE
I-465	93,143	95,153	2.16	1.09	10.27
I-64	18,731	17,478	-6.69	-7.21	11.11
I-65 Indy	91,548	90,691	-0.94	1.61	8.52
I-65 N	42,356	42,508	0.36	1.82	5.27
I-65 S	53,374	52,957	-0.78	0.06	6.11
I-69 N	40,232	38,915	-3.27	-5.26	11.65
I-70 E	41,084	43,393	5.62	1.08	15.29
I-70 Indy	88,086	93,082	5.67	2.19	15.73
I-70 W	31,319	30,090	-3.92	-6.18	7.86
I-74 E	24,568	25,631	4.33	2.60	14.94
I-74 W	18,690	19,487	4.26	3.46	21.28
I-80	64,835	67,949	4.80	-0.09	15.34
SR37 S	18,316	18,571	1.39	2.83	25.47
SR57	6,079	5,950	-2.11	1.05	17.80
SR67 S	10,487	10,705	2.08	-0.60	20.66
US231 S	6,674	6,497	-2.65	-1.33	22.75
US30	24,328	24,880	2.27	2.75	19.94
US31 N	22,507	22,198	-1.37	-1.24	14.88
US41 N	12,363	13,478	9.02	9.26	40.87
US41 S	20,610	20,059	-2.67	-5.17	19.66
Hoosier Heartland	8,561	8,789	2.66	1.98	21.68
I-164	19,537	16,165	-17.26	-15.57	20.82
I-469	19,485	18,645	-4.31	-4.15	9.80
US50	12,290	11,315	-7.93	-6.64	27.38
US20/US31 Bypass	23,117	22,101	-4.39	-2.68	9.78

Source: Bernardin, Lochmueller & Associates, Inc., 2004.

The overall performance by area type indicates that loading and VMT errors are within +/- 3% for most areas. % RMSE's are less than 35% for most area types as shown in **Table 23**, with a high accuracy in urban area and major employment district.

Table 23. Model Performance by Area Type (All Roads)

CLASS	Counts Avg.	Loading Avg.	% Error	VMT % Error	% RMSE
Maj Employment District	25,366	25,778	1.62	-0.58	28.47
Urban Areas	19,931	19,527	-2.03	-0.48	32.82
Suburban Areas	12,253	11,315	-7.65	-3.71	34.55
Rural Areas	5,375	5,512	2.55	2.04	37.13

Source: Bernardin, Lochmueller & Associates, Inc., 2004.

b. State Jurisdictional Highways

When considering only state jurisdictional highways, the ISTDM demonstrates an even higher accuracy. The systemwide % RMSE is much improved to 32% while loading and VMT errors are well balanced as shown in **Tables 24 and 25**. Error statistics for major corridors are identical to **Table 22** since they are all federal or state jurisdictional highways. All area types show less than or around 30% of RMSE as indicated in **Table 26**.

Table 24. Model Performance by Volume Group (State Highways)

CLASS	Counts Avg.	Loading Avg.	% Error	VMT % Error	% RMSE
1,001 to 2,000 AADT	1,472	1,831	24.35	25.84	72.21
2,001 to 3,000 AADT	2,512	2,915	16.04	17.43	55.96
3,001 to 4,000 AADT	3,561	3,669	3.02	3.17	38.72
4,001 to 5,000 AADT	4,477	4,593	2.58	3.26	38.93
5,001 to 6,000 AADT	5,472	5,476	0.08	-1.45	37.63
6,001 to 8,000 AADT	6,985	6,652	-4.76	-2.05	34.31
8,001 to 10,000 AADT	8,926	8,255	-7.51	-3.46	30.81
10,001 to 15,000 AADT	12,286	11,264	-8.31	-6.54	30.21
15,001 to 20,000 AADT	17,297	16,007	-7.46	-3.75	27.79
20,001 to 25,000 AADT	22,375	21,312	-4.75	-3.76	25.02
25,001 to 30,000 AADT	27,413	26,233	-4.31	-4.65	23.01
30,001 to 40,000 AADT	34,113	33,790	-0.95	2.01	20.94
40,001 to 50,000 AADT	43,944	44,664	1.64	-0.78	14.71
50,001 to 75,000 AADT	59,149	59,899	1.27	1.43	12.83
75,001 to 100,000 AADT	86,069	89,403	3.87	4.23	14.60
> 100,000 AADT	118,853	117,483	-1.15	-0.83	5.49
All	**10,276**	**10,054**	**-2.16**	**-0.14**	**32.75**

Source: Bernardin, Lochmueller & Associates, Inc., 2004.

Table 25. Model Performance by Functional Classification (State Highways)

CLASS	Counts Avg.	Loading Avg.	% Error	VMT % Error	% RMSE
R. Interstates (1)	28,689	28,213	-1.66	-1.96	10.68
R. Prin. Arterials (2)	9,126	9,019	-1.18	-0.06	24.84
R. Minor Arterials (6)	6,500	6,649	2.29	3.89	34.37
R. Major Collectors (7)	3,635	3,669	0.95	2.80	49.21
R. Minor Collectors (8)	3,928	7,895	100.96	95.80	118.56
R. Local Roads (9)	4,046	5,283	30.58	13.21	79.85
U. Interstates (11)	63,073	64,616	2.45	2.01	12.54
U. Freeways (12)	22,637	23,228	2.61	1.48	24.25
U. Prin. Arterials (14)	18,030	16,892	-6.31	-5.89	29.26
U. Minor Arterials (16)	8,865	7,899	-10.90	-8.34	46.02
U. Collectors (17)	7,272	8,335	14.63	8.87	19.45
U. Local Roads (19)	7,672	7,355	-4.13	1.25	15.59
All	**10,276**	**10,054**	**-2.16**	**-0.14**	**32.75**

Source: Bernardin, Lochmueller & Associates, Inc., 2004.

Table 26. Model Performance by Area Type (State Highways)

CLASS	Counts Avg.	Loading Avg.	% Error	VMT % Error	% RMSE
Maj Employment District	34,430	33,912	-1.51	-1.16	17.13
Urban Areas	22,040	21,465	-2.61	-0.52	25.44
Suburban Areas	13,778	12,664	-8.08	-3.68	31.24
Rural Areas	5,790	5,850	1.03	0.88	33.07

Source: Bernardin, Lochmueller & Associates, Inc., 2004.

The validation status of the ISTDM model is further visualized in **Figure 15**. This figure illustrates how much discrepancies exist between loaded volumes and counts from the final validated base year assignment. The map on the left side highlights 5,000+ vehicles/day (vpd) over-assigned links in red and 5,000+ vpd under-assigned links in blue. The map on the right side is with the threshold increased to 10,000+ vpd. Moving from the 5,000+ vpd map to the 10,000+ vpd map, much of the highlighted links disappear. These maps imply that loading errors of most links except the links in urbanized areas are less than +/- 10,000 vpd.

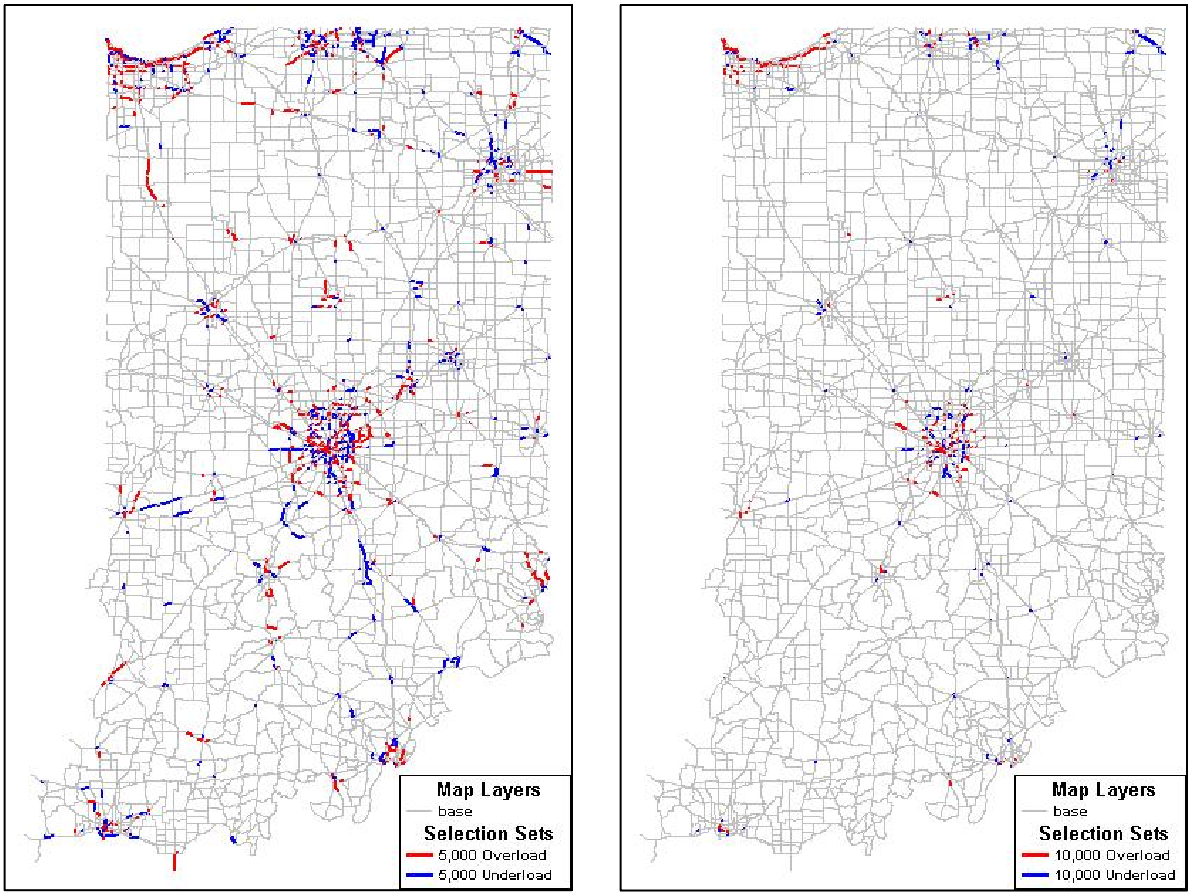


Figure 15. Base Year ISTDM Assignment Loading Errors
(**Source**: Bernardin, Lochmueller & Associates, Inc., 2004)

Figure 16 presents the final validated base year network color-coded with daily loaded volumes.

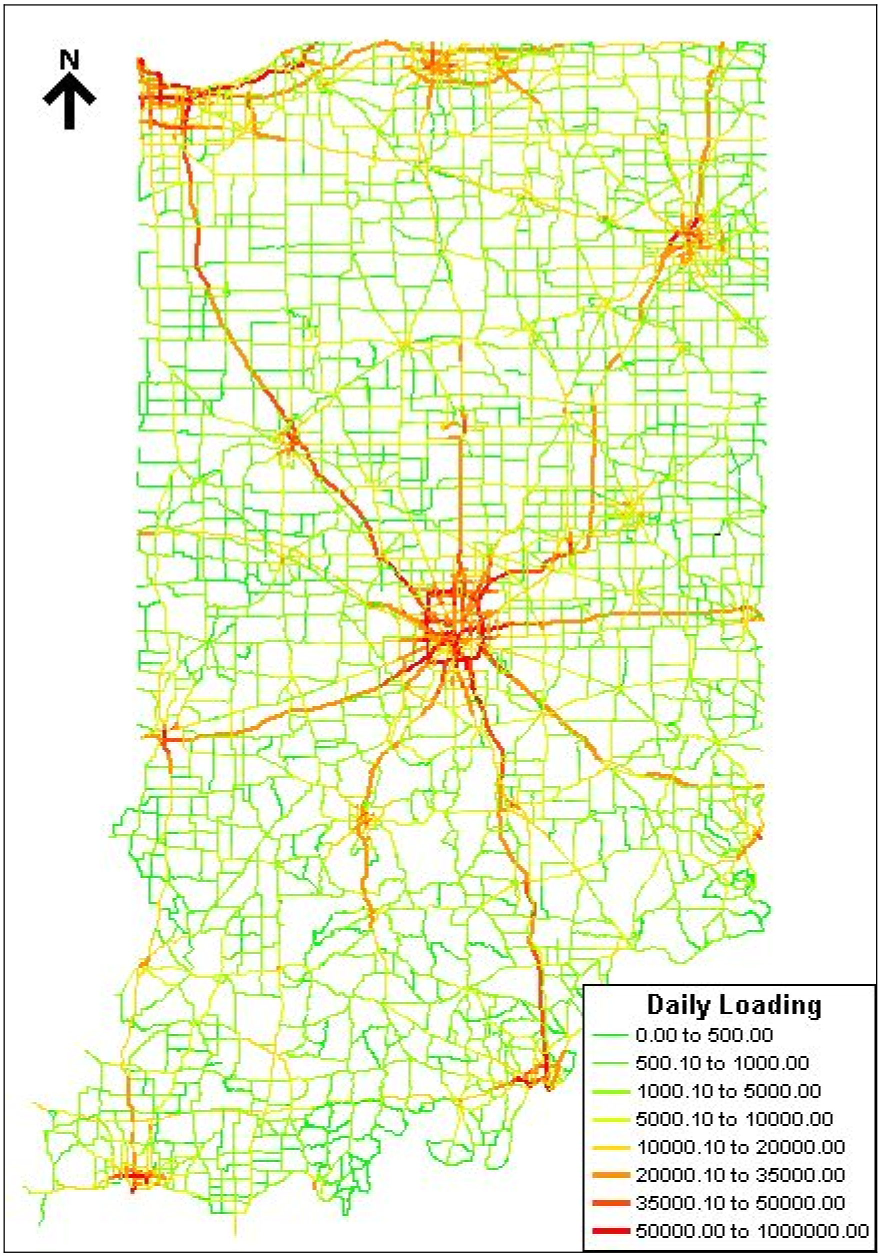


Figure 16. Base Year ISTDM Loaded Network
(**Source**: Bernardin, Lochmueller & Associates, Inc., 2004)

IX. POST-PROCESSING OF ISTDM

A. POST_ALT

The outputs of the travel model are the loaded volumes of autos and trucks (freight and non-freight) by direction on the various facilities in the model's roadway network. However, for planning and air quality purposes it is often important and helpful to further process the model outputs to produce estimates of speeds and level-of-service and to aggregate both these and the loadings (in terms of vehicle miles of travel) in various ways. All of this is done for the upgraded ISTDM by a post-processor to the travel model called POST_ALT. The POST_ALT program can be run after any model run, and produces estimates of level-of-service and average daily speeds for each link in the roadway network as well as a report which computes statistics for groupings of roadway segments in the network including functional classes, area types, counties, and corridors.

1. Estimation of Daily Average Speeds

The daily average speeds reported by POST_ALT are computed as the average of the hourly average speeds weighted by the hourly VMT. The hourly average speed for each link is calculated by using the Bureau of Public Roads (BPR) form of the volume delay function with link specific parameters as in the assignment. The volume delay function is used to adjust the link's free-flow speed on the basis of its hourly volume to capacity ratio to account for congestion related delay. The alpha and beta parameters for the BPR equation which are used in both the travel model's assignment procedure as well as the post-processing are coded on the network links. As explained in the previous Chapter, several sets of volume-delay parameters were applied in the ISTDM to different classes of roadway.

The estimation of link free-flow speeds is based on posted speed and facility type and is treated earlier in this report. The capacities used in the estimation of average speeds are also the same capacities used in the model proper developed using techniques from HCM 2000 and are described in detail in this report. The last input to the volume delay function, the hourly volume, is estimated by apportioning the model's assigned daily volume using a link specific hourly distribution created by adjusting the daily distribution from *1995 Indiana Household Travel Survey* using the link specific K and D factors coded on the links. The unadjusted hourly distribution of trips from the survey is displayed in **Table 27** and **Figure 17**.

Table 27. Distribution of Total Traffic by Hour

Hour of Day	Percent of Daily Traffic	Hour of Day	Percent of Daily Traffic
1 AM	0.47%	1 PM	4.77%
2 AM	0.36%	2 PM	5.13%
3 AM	0.26%	3 PM	8.62%
4 AM	0.36%	4 PM	9.60%
5 AM	1.61%	5 PM	9.22%
6 AM	6.55%	6 PM	5.13%
7 AM	8.01%	7 PM	3.99%
8 AM	6.24%	8 PM	2.90%
9 AM	4.61%	9 PM	2.95%
10 AM	4.41%	10 PM	3.06%
11 AM	4.61%	11 PM	1.71%
Noon	4.61%	Midnight	0.83%

Source: 1995 Indiana Household Travel Survey

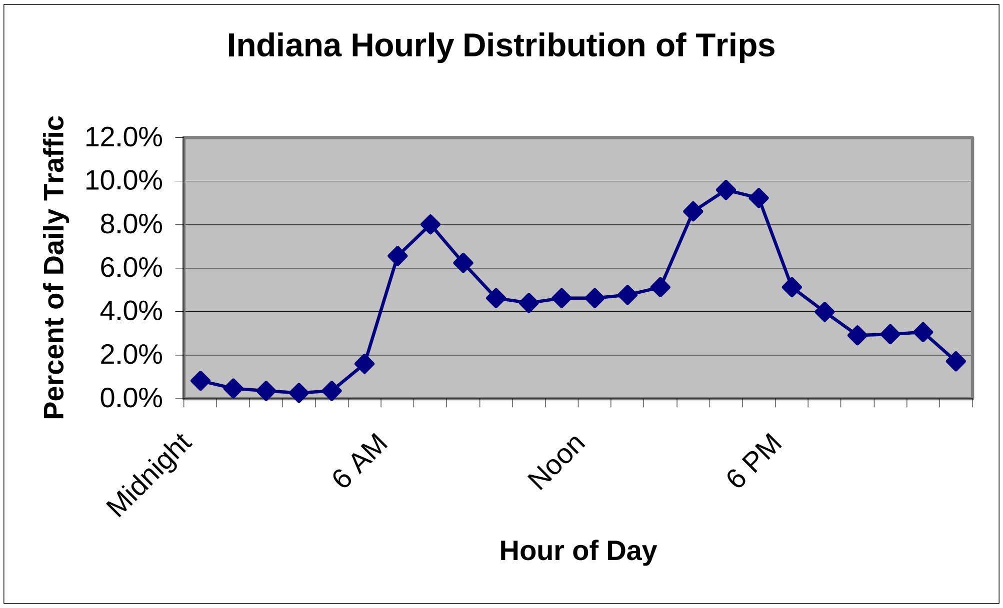


Figure 17. Indiana Hourly Distribution of Total Traffic
(**Source**: 1995 Indiana Household Travel Survey)

The K factor (percentage of daily traffic in the peak hour), and the D factor (percentage of traffic in the peak direction) link attributes, including their default values, are discussed more thoroughly in the following section on level of service estimation. For purposes of estimating hourly volumes, each link's D factor is applied for both the AM and PM peak hours and the average of the D factor and 0.5 (balanced flow) is assumed in the two shoulder hours of each peak. The K factor is used to adjust the survey distribution to reflect the more or less peaked character of traffic on each link.

It has become BLA's standard practice to calibrate POST_ALT to observed speed data whenever it is available. The speed estimation component of POST_ALT for ISTDM was calibrated to available observed daily average speed data collected in southwestern Indiana for the I-69 Tier 1 EIS and supplemented by a number of additional locations where observed speed data accompanied traffic counts sent to BLA for the validation of model. The speed data locations are displayed in **Figure 18**. Although the sample contained over a hundred observations on a wide variety of functional classes and facility types, all locations were in the southern half of the state and the urban areas are significantly under-represented in the sample. However, despite the limitations of the available data, it was useful in developing correction factors and evaluating the accuracy of the POST_ALT's daily average speeds. The corrections applied are largely associated with the 'under-modeling' of signal delay. Signal delay was intentionally underrepresented in the travel model proper since using true delays would result in the under-loading of signalized facilities. This may be due to a common psychological underestimation of the impact of signal delays on travel time and the way people in fact value time waiting at a traffic signal differently from time in motion in evaluating competing destination and route choices. Signal delay is therefore re-estimated in POST_ALT using a technique and parameters that differ slightly from those used in the model proper. This estimation also takes into account incremental signal delay in addition to uniform delay. The calibration process also revealed that it was advantageous to introduce factors to slightly adjust speeds for the observed differential in average speeds between basic facility types not captured by the free-flow speeds and volume-delay functions.

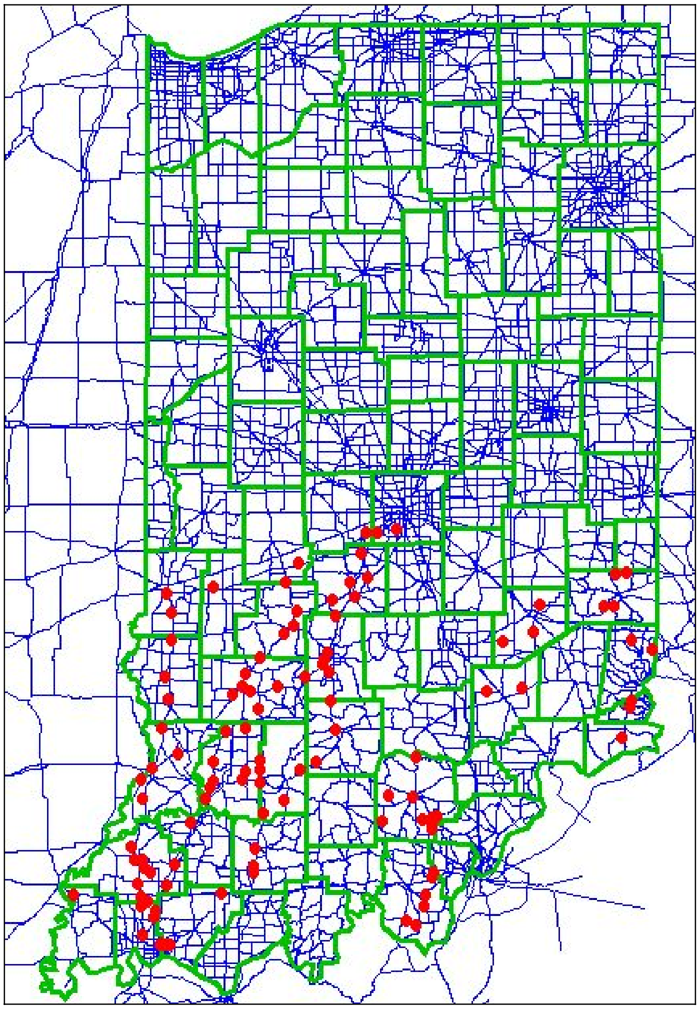


Figure 18. Observed Average Daily Speeds Locations
(**Source**: Bernardin, Lochmueller & Associates, Inc., 2004)

The final calibration resulted in a 23.78% root mean square error for average daily speeds. This represents exceptionally good agreement between the estimated and observed speeds. However, as the facilities with available observed speeds tend to experience less congestion (and associated speed variation) than the Indiana roadway network on the whole, a larger sample of observed speeds would almost certainly reveal greater error. Even so, the error could be considerably higher than the observed 24% RMSE and still be considered a very good speed model.

2. <u>Estimation of Level of Service</u>

The estimates of level of service produced by POST_ALT are provided for general system level planning purposes and are not intended to replace manual level of service analyses for corridor planning and design purposes. Due to a variety of factors including the general assumptions regarding the percent of traffic in the peak hour and peak direction, POST_ALT's estimates of level of service will not be as accurate as manual estimates for particular corridors which make use of corridor specific assumptions. It is therefore important that specific level of service analyses still be done for detailed planning when examining specific corridors and improvements.

The estimation of levels of service by any methodology is sensitive to several key assumptions. The three key assumptions for level of service analysis that are exogenous to this model are the analysis period, the percentage of daily traffic in the peak hour (K factor), and the percentage of traffic in the peak direction (D factor).

Consistent with previous versions for use with the statewide model, this version of POST_ALT uses an average peak hour as the analysis period. The average peak hour traffic derived from the demand model's average daily volumes would correspond to approximately the 150th to 200th highest hour annually. The levels of service returned by POST_ALT may, therefore, differ from a level of service produced by an analysis using a higher (design) hour or different length period (such as peak 15-minutes).

This version of POST_ALT allows the user to specify their assumption of K and D factors on the input roadway network used in the model. The default values provided with the network are displayed in **Tables 28** and **29**. The K factors were taken from the *Indiana State Highway Congestion Analysis Plan* produced by Purdue University for INDOT and FHWA in 1996. (Since these K factors differ from the K factor implied in the hourly distribution of traffic, the peak hour used for the level of service estimation may differ somewhat from the peak hour used in the estimation of daily average speeds.) The D factors were taken from the HCM 2000, with the exception of the intermediate urban factor which was simply interpolated as the midpoint.

Table 28. Default K factors

Functional Class	K factor
Rural Interstates	8.5%
Rural Arterials	8.2%
Rural Collectors & Locals	7.6%
Urban Interstates, Freeways, & Expressways	8.2%
Urban Arterials, Collectors, & Locals	8.0%

Source: Indiana State Highway Congestion Analysis Plan

Table 29. Default D factors

Functional Type	D factor
Urban Radial	65%
Urban Intermediate	59%
Urban Circumferential	53%
Rural	55%

Source: HCM 2000

If data on the peaking characteristics (K/D factors) of particular facilities is known or collected by the user, it can be entered in the network geographic layer and used by POST_ALT to produce more precise estimates of level of service. The default assumptions were chosen so as to produce a realistic but conservative estimation of deficiencies and not to represent a 'worst case scenario' approach. Alternate, but reasonable, assumptions could be made which would result in more lower levels of service. The approach taken here, however, has the advantage of yielding a greater certainty in the deficiencies that are reported since these assumptions have been made in such a way as to give facilities 'the benefit of the doubt' within reason.

Using the assumptions discussed above to arrive at a traffic volume for the analysis period, POST_ALT estimates and reports level of service using two alternative methods, volume to capacity ratio (v/c) breakpoints and the HCM 2000 criteria by facility type. The v/c breakpoint method was retained to provide consistency with earlier versions of POST_ALT, while the HCM 2000 method was introduced as a new best practice methodology. The two methods show some generally reasonable differences. The v/c breakpoint methodology is more likely to show greater deficiencies (lower levels of service) on freeways and fewer on rural two-lane highways; whereas, the HCM 2000 methodology is more likely to show the reverse. While the HCM 2000 method may be considered a generally more sensitive and refined methodology, the relative sensitivity of the two different methods to different underlying assumptions (definition of capacity, directional split, percent passing zone, etc.) could easily justify the use of the v/c breakpoint levels of service on particular facilities where the operative assumptions could bias the HCM 2000 method.

The breakpoints applied to the v/c ratio to assign level of service by this traditional method are displayed in **Table 30**. The HCM 2000 sets forth several sets of v/c breakpoints for certain facility types depending on particular characteristics of particular facilities within the type, while it sets forth no v/c breakpoints for other facility types. The set of v/c breakpoints which when applied to all facility types yielded the best agreement with the more complicated methodologies proscribed for the various facility types was identified through experimentation. The selected set was offered in the HCM 2000 for multilane highways with lower posted speeds in Exhibit 21-2.

Table 30. V/C Breakpoints for Level of Service

Level of Service	Minimum Volume/Capacity	Maximum Volume/Capacity
A		0.26
B	0.27	0.43
C	0.44	0.62
D	0.63	0.82
E	0.83	1.00
F	1.01	

Source: HCM 2000

The more sophisticated methodologies from HCM 2000 applied in POST_ALT include those set forth for freeways (basic) and multilane highways, rural two lane highways, and urban streets. The other criteria offered in the HCM 2000 (for freeway weaving sections, intersections, etc.) cannot be reasonably or meaningfully applied in POST_ALT given the level of information available from the travel demand model.

The criteria for determining level of service set forth in the HCM 2000 for both freeways and multilane highways is flow density. The same set of breakpoints is offered for both freeways and multilane highways and they do not vary with posted speed or other facility characteristics. The flow density breakpoints in passenger cars per lane mile are reproduced in **Table 31** from Exhibit 23-2 in the HCM 2000.

Table 31. HCM 2000 Level of Service Criteria for Freeways and Multilane Highways

Level of Service	Minimum Flow Density	Maximum Flow Density
A		11.00
B	11.01	18.00
C	18.01	26.00
D	26.01	35.00
E	35.01	45.00
F	45.01	

Source: HCM 2000

The HCM 2000 sets forth a dual set of criteria for determining level of service for rural two lane highways. The lower of two levels of service is used. However, the lowest level assigned by either criteria is LOS E and LOS F is defined separately for the facility type as an hourly flow rate of greater than 1,700 passenger cars per hour. The HCM 2000 dual criteria for rural two lane highways (with posted speeds of 55 mph) are reproduced from Exhibit 20-2 in **Table 32**. For rural two lane highways with posted speeds of less than 55 mph the average speed breakpoints were adjusted downward to represent the same percentage of posted speed threshold as for 55 mph posted facilities.

Table 32. HCM 2000 Level of Service Criteria for Rural Two Lane Highways

Level of Service	Percent Time Spent Following	Average Travel Speed
A	<= 35%	> 55 mph
B	35% - 50%	50 – 55 mph
C	50% - 65%	45 – 50 mph
D	65% - 80%	40 – 45 mph
E	> 80%	<= 45 mph

Source: HCM 2000

Percent time spent following is estimated in POST_ALT using Equations 20-6 and 20-7 from HCM 2000. A piecewise function of flow rate was developed to estimate the adjustment for combined effect of directional distribution of traffic and percentage of no-passing zones on percent time spent following on two way segments using Exhibit 20-12 and assuming a 55/45 directional split and 20% no-passing zones. The directional split assumption was made to be consistent with the default for rural facilities already introduced, and 20% no-passing zones was assumed because more conservative assumptions of no-passing zones seemed to yield higher percent times following and lower levels of service than were judged reasonable. The final equation set used in POST_ALT to estimate percent time spent following is displayed below.

$$PTSF = 100(1 - e^{-0.000879 v_p}) + f_{d/np}$$

$$\forall v_p \le 933,\ f_{d/np} = 7.625 + 0.0214 v_p - 0.0000255 {v_p}^2$$

$$\forall v_p > 933,\ f_{d/np} = 10.1589 - 0.006 v_p + 0.00000096 {v_p}^2$$

Where

PTSF	= percent time spent following
v_p	= passenger-car equivalent flow rate for analysis period
$f_{d/np}$	= adjustment for the combined effect of directional distribution of traffic and percentage of no-passing zones on percent time spent following

For urban streets HCM 2000 uses average speed as the criteria for determining level of service. However, the threshold average speeds for the levels of service vary depending on the free-flow speed of the facility. Curves were therefore fit to produce the threshold speed for each level of service based on the free-flow speed. The curves are displayed in **Figure 19**.

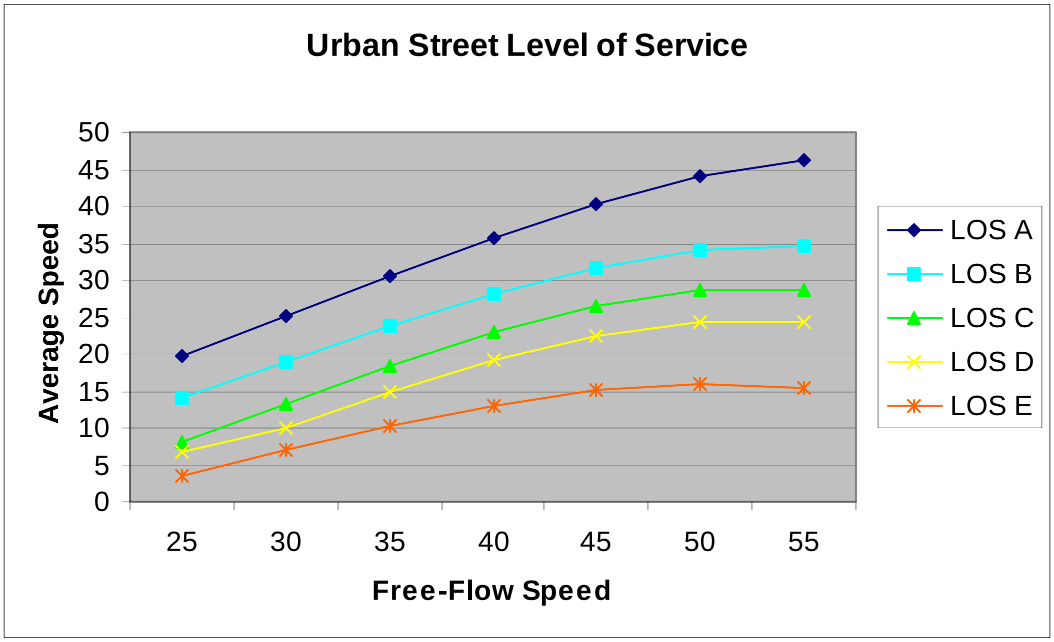


Figure 19. HCM 2000 Level of Service Criteria for Urban Streets
(**Source**: HCM 2000)

POST_ALT uses the model's free flow speeds and estimates the average speed for the analysis period by re-applying the Bureau of Public Roads (BPR) form of the volume delay function with link specific parameters as in the assignment as for the estimation of daily average speeds, only the volume used is that derived based on the level of service assumptions (K and D factors).

3. Estimation of Accidents

Accidents by severity are also estimated by POST_ALT. POST_ALT reports the number of fatal accidents, the number of injury accidents, and the number of property damage only (PDO) accidents, as well as total number of accidents for each functional class, area type, county, and for corridors that can be defined by the user. The numbers of accidents are estimated by applying average rates by functional class for Indiana (based on 1997-1999 statewide accident data) to the VMT on each roadway segment. Since this method is based on functional class and generally insensitive to actual roadway characteristics (it will treat all full access control facilities as FC 1, 11, or 12) and levels of congestion, it should be viewed as a very rough approximation, but it is provided to offer some sense of the relative contribution of various corridors and counties to Indiana's total traffic accidents. More sophisticated tools such as NET_BC or HERS should be used for project level evaluations, but POST_ALT's safety statistics are offered so as to be able to include some safety considerations in wider systems analyses.

4. Estimation of Other Traffic Statistics

In addition to the calculation of average daily speeds, POST_ALT computes a number of additional traffic statistics. The calculation of these statistics are straightforward, such as the computation of vehicle miles of travel (VMT) from roadway segment lengths and loadings and vehicle hours of travel (VHT) from link loadings and the hourly speeds calculated in the process of producing the average daily speed.

Statistics are computed and reported for both individual roadway segments and in aggregate for each functional class, area type, county, and for corridors that can be defined by the user. The statistics generated are listed in **Table 33**. These statistics are provided as potential additional performance measures or evaluation criteria in order to make the ISTDM a more valuable planning tool. By generating more than a single statistic or criteria such as level of service alone, a more complete picture of traffic can be conveyed and more than one dimension of problems evaluated. In particular, in analysis of deficiencies, it is important that there are evaluation criteria that can capture both the severity and the magnitude of deficiencies. For instance, level of service as a measure of the severity of deficiency can be used together with total delay from congestion which is a measure of the magnitude of a deficiency. Safety criteria can add an additional dimension.

Table 33. Statistics Generated by POST_ALT

Statistics Reported on Roadway Segments	Statistics Reported in Aggregate for Functional Classes, Area Types, Counties, and Corridors	Additional Statistics Reported for Corridors when Applicable*
Average daily speed	Vehicle miles of travel (VMT)	Average peak hour flow
Average daily travel time	VMT by autos	Average peak hour flow density
Level of service (by v/c ratio)	VMT by freight trucks	Average percent time spent following
Level of service (by HCM 2000 method)	VMT by non-freight trucks	Level of service (by HCM 2000 method)
Daily volume to capacity ratio	Vehicle hours of travel (VHT)	Level of service (by v/c ratio)
Peak hour volume to capacity ratio	VHT by autos	
Peak hour flow rate	VHT by freight trucks	
Peak hour speed	VHT by non-freight trucks	
Peak hour flow density (for freeways and multilane hwys.)	Average daily speed	
Percent time following (for rural two lane highways)	Total delay from congestion	
Congestion delay	Percent of travel time due to congestion delay	
Percent of travel time due to congestion delay	Average daily v/c ratio	
	Average peak hour v/c ratio	
	Number of fatal accidents	
	Number of injury accidents	
	Number of PDO accidents	
	Total number of accidents	

* In order for average peak hour flow density, average percent time spent following, and the HCM 2000 method level of service to be calculated and reported for a corridor, the entire corridor must be of the same facility type so that the same criteria can be applied.
Source: Bernardin, Lochmueller & Associates, Inc., 2004

POST_ALT also tabulates certain system-wide statistics. These include the VMT and VHT by level of service (using the HCM 2000 method) and the Efficient System Performance Indices (ESPI). The ESPI are a set of performance measures developed by Bernardin, Lochmueller & Associates to capture the level of system-wide congestion in a single number or small set of numbers. The ESPI are calculated and can be used either with VMT or VHT as the measure of travel. POST_ALT computes an ESPI for each mode individually, as well.

The formula that defines the ESPI are shown below.

$$ESPI_{VMT} = 10 \cdot \frac{VMT_{Total}}{VMT_{v/c>.70} + VMT_{v/c>.99}}$$

$$ESPI_{VHT} = 10 \cdot \frac{VHT_{Total}}{VHT_{v/c>.70} + VHT_{v/c>.99}}$$

As the name implies, the ESPI are a measure of system efficiency, and as the amount of travel (VMT or VHT) under congested (v/c > 0.70) or heavily congested (v/c > 0.99) conditions increases, the ESPI decreases. The higher the ESPI number, the greater the system efficiency and the lower the congestion. Since it is a normalized value, the ESPI also has the advantage of being able to be used for comparison between different models or study areas. For example, the ESPI from model runs from the previous version of the statewide model could be compared to the ESPI from the current model or for another states. Because they capture the effects of diversion, system-wide measures such as the ESPI and system-wide breakouts by level of service are helpful and sometimes important in evaluating the impact of modeled improvements not only on the improved corridor(s) in particular but on the transportation network as a whole.

X. SOCIOECONOMIC FORECASTS

Since the traffic forecasts ultimately produced by the ISTDM are driven by the socioeconomic data supplied as inputs to the model, particular attention was given to producing the best possible socioeconomic forecasts for the new version of the ISTDM. The forecast year for the I-69 model was 2025. New forecasts for 2030 were produced for the upgraded ISTDM at the new level of zonal detail using the new employment categories. Intermediate year 2015 forecasts were also produced based on linear interpolation at the zonal level between the 2000 and 2030 datasets.

The new 2030 zonal level forecasts of population were developed in two steps. First county control totals were developed and then county growth was allocated to the TAZ within each county using an accessibility based regression model. The 2030 zonal employment forecasts were developed similarly by first establishing county control totals for total employment and then distributing growth to the TAZ within each county using another accessibility based regression model; however, in the case of employment a third step is also necessary to break out the total employment into the various industrial categories. This was accomplished by a Fratar process. Wherever detailed forecasts were supplied by MPO's for the TAZ in their urban models, these were used instead of or in conjunction with the regression models to allocated the county control totals of population and employment. Additional socioeconomic variables including households, household size, household auto ownership, and household income were forecast using a variety of methods described in detail in the following sections.

A. POPULATION FORECASTS

In the development of year 2030 population forecasts, BLA examined Woods & Poole Economics forecasts (released in April of 2004) and Indiana State Data Center forecasts by county, and the Regional Economics Model, Inc. (REMI) forecast for the State of Indiana together with historic growth trends.

The attached population table shows the Woods & Poole and STATS Indiana (i.e., Indiana State Data Center) population forecasts for the year 2030 by county. The REMI forecast for the State of Indiana in the year 2030 is 7,280,339 persons. In the past, Woods & Poole forecasts have been used as a foundation for the Indiana and Kentucky statewide travel models because the employment and population forecasts are interrelated. Woods & Poole begins with the US Bureau of Economic Analysis employment forecasts for States and metropolitan areas, allocates employment to individual counties, and generates associated demographic information. Each state has a designated State Data Center that forecasts population for use in planning studies by Federal, State and local agencies. These forecasts are generally based on regression analysis techniques of historical population data without a direct relationship to the economy.

BLA has also generated 2030 forecasts based on:

- The historical 30-year population growth rate from 1970 to 2000 applied to the year 2000 population.
- The historical 10-year population rate from 1990 to 2000 applied to the year 2000 population for each decade to the year 2030.

Examining the growth rates from Woods & Poole, STATS Indiana, past three decades, the last decade and from 2000 to 2003, BLA selected the year 2030 population forecast for each county that was most consistent with historical growth rates. In general, the highest population forecast was chosen for counties that had high growth rates over the past three decades, last decade and last three years (defying the economic downturn). The lowest population forecasts were chosen for counties (predominately rural) that lost population for the past three decades, last decade, and lost population over the last three years. Intermediate forecasts were chosen for counties that fell in between. In the case of Delaware County, BLA (in the past) and the State Data Center have independently forecasted future growth despite past poor growth rates.

Finally, the REMI population forecast was chosen as the statewide control total because it falls between the Woods & Poole forecast and the Indiana State Data Center forecast and because REMI forecasts are the foundation for the economic benefits analyses of transportation investments associated with the Indiana Long Range Transportation Plan. Finally, the forecasts were chosen for consistent characteristics by BLA to come as close as possible to the REMI Indiana forecast.

Table 34. County Total Population Forecasts Provided for Review

NAME	Woods & Poole		STATS_Indiana		30-yr Historical*	10-yr Historical**	BLA Proposed
	July 1, 2000	July 1, 2030	April 1, 2000	July 1, 2030	July 1, 2030	July 1, 2030	July 1, 2030
INDIANA	6,091,950	7,644,046	6,080,485	7,024,457	7,129,782	7,859,903	7,281,803
ADAMS, IN	33,620	40,769	33,625	37,573	42,070	41,826	37,573
ALLEN, IN	332,720	409,732	331,849	391,694	393,692	435,620	409,732
BARTHOLOMEW, IN	71,703	93,298	71,435	75,255	89,827	97,986	89,827
BENTON, IN	9,385	8,691	9,421	8,908	7,851	9,325	7,851
BLACKFORD, IN	14,014	13,268	14,048	13,354	12,391	13,957	12,391
BOONE, IN	46,386	76,930	46,107	64,754	69,281	75,424	76,930
BROWN, IN	15,001	23,248	14,957	16,384	24,773	17,804	16,384
CARROLL, IN	20,171	23,153	20,165	21,240	22,936	24,534	21,240
CASS, IN	40,987	43,809	40,930	42,227	41,467	49,044	41,467
CLARK, IN	96,802	124,448	96,472	108,002	123,078	125,569	124,448
CLAY, IN	26,557	29,258	26,556	27,813	29,468	32,526	27,813
CLINTON, IN	33,978	39,909	33,866	36,268	37,670	43,495	36,268
CRAWFORD, IN	10,799	14,355	10,743	13,834	14,442	13,508	13,834
DAVIESS, IN	29,824	32,922	29,820	33,408	33,432	37,256	32,922
DEARBORN, IN	46,326	75,141	46,109	54,339	72,581	72,357	72,581
DECATUR, IN	24,566	27,056	24,555	26,860	26,529	27,402	26,529
DE KALB, IN	40,397	54,517	40,285	46,344	52,774	57,417	46,344
DELAWARE, IN	118,682	118,303	118,769	130,739	109,084	116,034	130,739
DUBOIS, IN	39,711	46,740	39,674	40,880	50,931	49,660	46,740
ELKHART, IN	183,549	233,099	182,791	222,040	265,165	277,298	233,099
FAYETTE, IN	25,550	27,163	25,588	24,425	24,938	24,292	24,292
FLOYD, IN	70,897	92,544	70,823	73,843	90,273	92,095	90,273
FOUNTAIN, IN	17,929	18,003	17,954	17,836	17,631	18,370	17,631
FRANKLIN, IN	22,225	30,286	22,151	25,819	29,057	30,980	25,819
FULTON, IN	20,560	23,728	20,511	22,011	24,830	26,031	22,011
GIBSON, IN	32,549	34,670	32,500	33,600	34,747	34,345	34,670
GRANT, IN	73,265	69,373	73,403	74,206	64,057	70,995	64,057
GREENE, IN	33,210	40,070	33,157	33,359	40,944	42,210	33,359
HAMILTON, IN	185,374	369,896	182,740	413,198	621,199	562,146	413,198
HANCOCK, IN	55,655	97,175	55,391	74,352	87,839	91,830	91,830
HARRISON, IN	34,502	56,167	34,325	41,584	57,988	49,860	49,860
HENDRICKS, IN	105,390	242,970	104,093	185,614	203,253	223,879	242,970
HENRY, IN	48,463	49,583	48,508	46,269	44,690	49,577	44,690
HOWARD, IN	84,972	90,017	84,964	88,271	86,776	98,019	86,776
HUNTINGTON, IN	38,099	41,884	38,075	40,912	41,482	46,642	40,912
JACKSON, IN	41,409	51,354	41,335	44,259	51,576	53,279	44,259
JASPER, IN	30,197	44,462	30,043	34,363	44,408	48,645	34,363
JAY, IN	21,806	23,028	21,806	22,458	20,170	22,700	20,170
JEFFERSON, IN	31,726	37,146	31,705	35,079	37,246	37,821	37,146

NAME	Woods & Poole		STATS_Indiana		30-yr Historical*	10-yr Historical**	BLA Proposed
	July 1, 2000	July 1, 2030	April 1, 2000	July 1, 2030	July 1, 2030	July 1, 2030	July 1, 2030
JENNINGS, IN	27,695	40,697	27,554	34,457	39,226	41,365	34,457
JOHNSON, IN	115,972	197,066	115,209	163,442	218,539	222,982	197,066
KNOX, IN	39,177	38,016	39,256	40,571	37,018	37,326	37,018
KOSCIUSKO, IN	74,237	96,268	74,057	83,981	114,235	104,127	83,981
LAGRANGE, IN	34,945	49,818	34,909	49,097	58,396	54,264	49,097
LAKE, IN	484,693	551,342	484,564	504,808	429,956	512,118	504,808
LA PORTE, IN	110,193	115,463	110,106	114,371	115,176	119,579	114,371
LAWRENCE, IN	45,945	53,930	45,922	46,342	55,468	55,875	46,342
MADISON, IN	133,278	145,769	133,358	124,413	128,309	141,506	124,413
MARION, IN	860,552	997,665	860,454	947,055	932,847	1,065,537	932,847
MARSHALL, IN	45,252	57,249	45,128	52,848	58,370	54,733	54,733
MARTIN, IN	10,355	10,330	10,369	10,403	9,789	10,355	9,789
MIAMI, IN	36,172	36,189	36,082	38,176	33,256	33,775	33,775
MONROE, IN	120,666	168,778	120,563	149,228	170,707	159,149	149,228
MONTGOMERY, IN	37,624	45,668	37,629	40,632	41,726	48,090	40,632
MORGAN, IN	66,888	96,211	66,689	76,238	100,976	105,532	96,211
NEWTON, IN	14,555	16,374	14,566	14,629	18,267	17,826	14,629
NOBLE, IN	46,446	63,558	46,275	53,872	68,488	77,340	53,872
OHIO, IN	5,642	7,302	5,623	6,350	7,397	6,623	6,350
ORANGE, IN	19,322	21,610	19,306	21,268	21,984	22,146	21,268
OWEN, IN	21,896	33,239	21,786	25,876	39,219	39,020	25,876
PARKE, IN	17,237	20,947	17,241	16,940	20,316	23,381	16,940
PERRY, IN	18,885	19,647	18,899	18,837	18,711	18,268	18,268
PIKE, IN	12,816	13,903	12,837	13,618	13,396	13,824	13,396
PORTER, IN	147,229	220,034	146,798	164,915	248,099	208,433	208,433
POSEY, IN	27,073	29,836	27,061	25,841	33,699	30,492	29,836
PULASKI, IN	13,750	15,718	13,755	14,208	15,089	17,378	14,208
PUTNAM, IN	36,106	53,992	36,019	42,072	48,288	56,487	42,072
RANDOLPH, IN	27,397	27,379	27,401	27,238	25,962	28,163	25,962
RIPLEY, IN	26,647	34,525	26,523	30,703	33,435	32,840	30,703
RUSH, IN	18,219	17,515	18,261	17,611	16,347	18,617	16,347
ST. JOSEPH, IN	265,881	310,100	265,559	297,557	288,396	325,634	288,396
SCOTT, IN	23,049	30,889	22,960	26,933	30,868	29,535	26,933
SHELBY, IN	43,597	51,499	43,445	46,220	50,112	53,779	46,220
SPENCER, IN	20,410	22,607	20,391	20,422	24,290	23,241	20,422
STARKE, IN	23,542	26,347	23,556	23,856	28,763	26,054	23,856
STEUBEN, IN	33,312	45,720	33,214	37,298	54,885	54,314	37,298
SULLIVAN, IN	21,745	24,006	21,751	23,398	23,781	31,218	23,398
SWITZERLAND, IN	9,093	14,488	9,065	11,317	13,071	13,771	11,317
TIPPECANOE, IN	149,335	203,530	148,955	185,580	203,370	212,307	203,530
TIPTON, IN	16,558	17,921	16,577	16,075	16,485	17,969	16,075
UNION, IN	7,350	8,433	7,349	7,421	8,206	8,529	7,421
VANDERBURGH, IN	171,848	181,622	171,922	187,158	175,055	193,287	181,622
VERMILLION, IN	16,778	17,848	16,788	15,791	16,773	16,823	15,791
VIGO, IN	105,722	104,542	105,848	115,796	97,709	104,948	104,542
WABASH, IN	34,978	35,118	34,960	35,849	34,395	34,652	34,395
WARREN, IN	8,446	9,086	8,419	9,106	8,169	9,199	8,169
WARRICK, IN	52,571	71,212	52,383	59,081	98,449	78,773	71,212
WASHINGTON, IN	27,268	36,396	27,223	32,083	38,506	39,361	32,083
WAYNE, IN	71,043	69,594	71,097	69,541	63,848	68,513	63,848
WELLS, IN	27,617	32,081	27,600	28,546	31,998	32,892	28,546
WHITE, IN	25,241	28,738	25,267	26,437	30,377	31,757	28,738
WHITLEY, IN	30,746	38,066	30,707	35,578	40,356	40,940	38,066

Notes: * 1970 to 2000 growth rate applied to 2000 population to forecast 2030 population
** 1990 to 2000 growth rate applied to 2000 population to forecast 2030 population

The proposed forecasts were offered for reviewed by INDOT, the MPO's, the RPO's, and other interested parties. In response to comments, BLA made some minor alterations to and shifts between the county forecasts to arrive at the final values displayed in **Table 35**.

Table 35. Adopted County Total Population Forecasts

NAME	Population in TAZ			NAME	Population in TAZ		
	2000	2015	2030		2000	2015	2030
INDIANA	**6,063,076**	**6,696,428**	**7,332,109**				
ADAMS, IN	33,650	37,272	40,910	LAWRENCE, IN	45,952	46,136	46,341
ALLEN, IN	331,818	377,082	422,446	MADISON, IN	133,415	139,598	145,839
BARTHOLOMEW, IN	71,557	80,706	89,886	MARION, IN	859,031	906,390	953,808
BENTON, IN	9,412	8,646	7,898	MARSHALL, IN	45,098	49,875	54,691
BLACKFORD, IN	14,006	13,180	12,369	MARTIN, IN	10,320	10,024	9,735
BOONE, IN	46,164	61,586	77,056	MIAMI, IN	36,054	34,849	33,658
BROWN, IN	15,304	16,018	16,740	MONROE, IN	120,206	139,549	158,921
CARROLL, IN	20,206	20,732	21,276	MONTGOMERY, IN	37,616	39,638	41,701
CASS, IN	40,925	41,259	41,614	MORGAN, IN	66,683	81,624	96,597
CLARK, IN	96,294	109,766	123,281	NEWTON, IN	14,574	14,579	14,600
CLAY, IN	26,572	27,196	27,840	NOBLE, IN	46,222	49,995	53,795
CLINTON, IN	33,771	35,629	37,516	OHIO, IN	5,413	5,735	6,065
CRAWFORD, IN	10,649	12,123	13,612	ORANGE, IN	19,328	20,316	21,320
DAVIESS, IN	29,720	31,206	32,711	OWEN, IN	21,782	23,825	25,879
DEARBORN, IN	45,852	59,236	72,658	PARKE, IN	17,305	17,127	16,963
DECATUR, IN	24,517	25,481	26,455	PERRY, IN	18,229	18,193	18,179
DE KALB, IN	40,270	46,503	52,768	PIKE, IN	13,152	13,428	13,717
DELAWARE, IN	118,869	124,838	130,871	PORTER, IN	145,069	154,594	164,152
DUBOIS, IN	39,626	43,112	46,614	POSEY, IN	27,021	28,428	29,852
ELKHART, IN	182,249	207,212	232,226	PULASKI, IN	13,764	13,977	14,200
FAYETTE, IN	25,576	24,937	24,310	PUTNAM, IN	36,040	39,097	42,170
FLOYD, IN	72,176	82,445	92,730	RANDOLPH, IN	27,355	26,644	25,962
FOUNTAIN, IN	17,949	17,800	17,674	RIPLEY, IN	26,496	28,566	30,655
FRANKLIN, IN	22,155	23,988	25,839	RUSH, IN	18,315	17,322	16,344
FULTON, IN	20,479	21,214	21,966	ST. JOSEPH, IN	266,042	288,303	310,629
GIBSON, IN	32,264	33,464	34,682	SCOTT, IN	22,899	24,887	26,892
GRANT, IN	73,378	68,724	64,092	SHELBY, IN	43,419	44,827	46,250
GREENE, IN	33,181	34,181	35,198	SPENCER, IN	20,491	20,489	20,515
HAMILTON, IN	182,761	297,794	412,864	STARKE, IN	23,485	23,637	23,804
HANCOCK, IN	55,717	73,988	92,285	STEUBEN, IN	33,200	35,238	37,298
HARRISON, IN	34,528	42,374	50,241	SULLIVAN, IN	21,785	22,602	23,440
HENDRICKS, IN	104,767	164,557	224,369	SWITZERLAND, IN	9,060	10,224	11,396
HENRY, IN	48,479	46,572	44,691	TIPPECANOE, IN	148,979	176,220	203,500
HOWARD, IN	85,017	87,535	90,077	TIPTON, IN	16,567	16,332	16,105
HUNTINGTON, IN	38,006	42,231	46,492	UNION, IN	7,344	7,363	7,390
JACKSON, IN	41,347	42,816	44,309	VANDERBURGH, IN	171,943	178,644	185,371
JASPER, IN	30,067	32,249	34,451	VERMILLION, IN	16,740	16,172	15,623

NAME	Population in TAZ			NAME	Population in TAZ		
	2000	2015	2030		2000	2015	2030
JAY, IN	21,874	21,068	20,285	VIGO, IN	105,761	105,088	104,440
JEFFERSON, IN	31,665	34,417	37,182	WABASH, IN	35,054	34,769	34,502
JENNINGS, IN	27,624	31,083	34,552	WARREN, IN	8,434	8,310	8,196
JOHNSON, IN	115,452	156,794	198,161	WARRICK, IN	52,330	61,765	71,227
KNOX, IN	39,310	38,668	38,048	WASHINGTON, IN	27,248	29,694	32,161
KOSCIUSKO, IN	74,114	79,209	84,352	WAYNE, IN	71,083	67,399	63,757
LAGRANGE, IN	34,929	41,928	48,948	WELLS, IN	27,615	29,837	32,082
LAKE, IN	471,203	485,760	500,384	WHITE, IN	25,169	25,694	26,250
LA PORTE, IN	107,764	110,330	112,934	WHITLEY, IN	30,776	34,517	38,273

The final forecast population growth (or decline) was then allocated among the TAZ in each county using a regression model. The regression model was developed by regressing the year 2000 population against 1990 socioeconomic variables and actually predicted total population. The independent regressor variables lagged from the previous time period included Total Population, Total Households, Population Density, Population Under Age 17, Percent of Households with Head of Household over Age 65, Household Workers, Average Household Income, Accessibility to Wealth (by place of residence), Accessibility to Unoccupied Housing Units, Accessibility to Schools, Accessibility to University Enrollment, Travel Time to Nearest City Center, Travel Time to Nearest Airport, and Travel Time to Nearest Major Arterial. The regression equation included several terms comprised of these variables and their interactions. Each term had an F statistic resulting in a significance of better than 0.01. The r-squared for the regression equation was 0.982 and the correlation between the modeled and actual 1990 to 2000 change in population was 0.842. The model was used to estimate the 2000 population and the 2030 population. The estimated change in population from the regression model was expressed as a change in the zonal share of the county total population. One half of this change in zonal share of county total population was then applied to the zone's actual year 2000 share of county total population. The resulting shares were applied to the forecast county control total to breakout the population forecast to the zones. Only half the modeled shift in zonal share of county population predicted by the regression model was applied to bias the final allocation towards the existing distribution of population given the inherent uncertainty in land use forecasting.

Population forecasts for counties in Kentucky, Michigan, and Illinois were taken directly from their respective state data centers. Populations for counties in Ohio were taken from the Ohio Statewide Travel Demand Model. The distribution of population among TAZ within the few counties with multiple TAZ outside Indiana was held constant.

B. EMPLOYMENT FORECAST

In the development of year 2030 employment forecasts, BLA examined Woods & Poole Economics forecasts (released in April of 2004) and the Regional Economics Model, Inc. (REMI) forecast for the State of Indiana, historic trends, and the historic relationship between population and employment.

Having generated independent employment and population forecasts in the past, BLA reviewed labor force participation forecasts at the National level generated by the US Bureau of Labor Statistics and for Indiana generated by BLA. Contrary to the Woods & Poole forecasts, these sources show a future decline in the labor force participation consistent with that of the REMI employment and population forecasts. It should also be noted that Woods & Poole shows no employment loss for any county in Indiana despite forecasted population declines in the most rural Indiana counties. Thus, the REMI employment forecast of 4,188,723 employees was chosen as the statewide control total because of the better relationship of employment to population and because REMI forecasts are also the foundation for the economic benefits analyses of transportation investments associated with the Indiana Long Range Transportation Plan.

Because Woods & Poole was the only available source for employment forecasts for individual counties, BLA has also generated variations on the 2030 forecasts as shown in **Table 36**:

- "Total population driven" is based on BLA proposed 2030 population times the ratio of year 2000 population to year 2000 employment, with an adjustment to the REMI statewide total reflecting an adjustment is the labor force participation rate.
- "2030 share" is the ratio of the Woods & Poole year 2030 employment forecast for each county to the Woods & Poole Indiana 2030 employment forecast factored down to the REMI 2030 employment forecast for Indiana.
- "30-Year Population Change" starts with the ratio of the BLA proposed 30-year population change for each county to the Woods & Poole 30-year population change for each county, applies this ratio to the Woods & Poole 30-year employment change, adds the adjusted 30-year employment change to the year 2000 employment, and adjusts the sum of all counties to the REMI 2030 employment forecast for Indiana. Whenever the change of population is negative for an individual county, the "total population driven" method is substituted.

Examining the employment forecast options, BLA chose the employment forecast for each county consistent population growth of the county and the metropolitan economy. The highest employment forecast was chosen for metropolitan counties with a strong historical growth rate where population growth is occurring within the county without spilling over into adjacent counties -- such as Allen County, Elkhart County, St. Joseph County and Tippecanoe County. When a metropolitan county is the employment center for the region and experiencing less population growth than other counties in the metropolitan area, a higher employment forecast was chosen than one implied by population growth – such as Howard County, Lake County, Marion County, Porter County, Vanderburgh County and Vigo County. When a county in a metropolitan area is a concentration of bedroom communities, a middle employment forecast was chosen to reflect supportive residential services growth and to reflect growth in the base economy in the county that is the economic center of the region – such as Clark County, Dearborn County, Floyd County, Franklin County, Hendricks County, Johnson County, and Warrick County. The lowest employment forecast was chosen for counties with population loss or little population growth. Finally, county forecasts were chosen for consistent characteristics by BLA to come as close as possible to the REMI Indiana forecast.

Table 36. County Total Employment Forecasts Provided for Review

NAME	Woods & Poole		Total Population Driven*	2030 share**	30-yr Population Change***	BLA Proposed
	July 1, 2000	July 1, 2030	July 1, 2030	July 1, 2030	July 1, 2030	July 1, 2030
INDIANA	3,688,224	5,017,161	4,188,723	4,188,723	4,188,723	4,188,825
ADAMS, IN	22,982	30,811	24,582	25,723	24,960	24,582
ALLEN, IN	233,884	292,068	275,661	243,841	266,929	275,661
BARTHOLOMEW, IN	53,183	76,084	63,767	63,521	66,171	63,767
BENTON, IN	4,954	6,172	3,966	5,153	**3,787**	3,787
BLACKFORD, IN	6,404	7,529	5,419	6,286	**5,175**	5,175
BOONE, IN	24,025	41,304	38,135	34,484	37,749	34,484
BROWN, IN	6,337	10,768	6,624	8,990	6,471	6,471
CARROLL, IN	10,536	15,469	10,618	12,915	11,245	10,618
CASS, IN	22,562	28,006	21,847	23,382	21,467	21,467
CLARK, IN	59,053	84,397	72,661	70,461	77,133	70,461
CLAY, IN	12,481	15,783	12,510	13,177	12,810	12,510
CLINTON, IN	15,352	19,510	15,684	16,288	15,498	15,498
CRAWFORD, IN	4,094	6,056	5,020	5,056	5,272	5,020
DAVIESS, IN	16,260	19,314	17,179	16,125	17,652	16,125
DEARBORN, IN	21,002	36,679	31,493	30,623	32,249	30,623
DECATUR, IN	18,247	25,667	18,860	21,429	22,023	18,860
DE KALB, IN	28,329	38,334	31,105	32,004	29,742	31,105
DELAWARE, IN	70,006	91,467	73,809	76,364	**70,480**	76,364
DUBOIS, IN	35,857	47,622	40,393	39,759	43,523	39,759
ELKHART, IN	148,821	181,015	180,887	151,126	165,434	180,887
FAYETTE, IN	13,872	15,888	12,623	13,265	**12,054**	12,054
FLOYD, IN	36,968	53,094	45,051	44,327	46,978	44,327
FOUNTAIN, IN	8,489	9,942	7,990	8,300	**7,630**	7,630
FRANKLIN, IN	7,106	10,654	7,901	8,895	7,940	7,901
FULTON, IN	11,118	12,815	11,392	10,699	10,871	10,699
GIBSON, IN	17,173	21,793	17,507	18,195	19,917	19,917
GRANT, IN	38,547	44,573	32,256	37,213	**30,801**	30,801
GREENE, IN	12,713	17,522	12,222	14,629	11,714	11,714
HAMILTON, IN	110,238	220,814	235,177	184,353	225,523	184,353
HANCOCK, IN	24,660	43,839	38,943	36,600	37,809	38,943
HARRISON, IN	17,075	26,971	23,617	22,518	22,017	22,017
HENDRICKS, IN	47,744	121,259	105,348	101,237	110,822	105,348
HENRY, IN	20,934	26,576	18,476	22,188	**17,643**	17,643
HOWARD, IN	57,963	71,441	56,654	59,645	57,378	59,645
HUNTINGTON, IN	21,422	26,270	22,017	21,932	22,871	22,017
JACKSON, IN	26,655	37,660	27,267	31,442	27,243	27,243
JASPER, IN	16,045	24,774	17,475	20,683	16,994	16,994
JAY, IN	10,595	12,922	9,379	10,788	**8,956**	8,956
JEFFERSON, IN	17,938	23,347	20,101	19,492	21,337	19,492
JENNINGS, IN	12,006	18,883	14,296	15,765	14,241	14,241
JOHNSON, IN	58,007	99,939	94,339	83,437	91,337	83,437
KNOX, IN	23,096	28,753	20,887	24,005	**19,945**	19,945
KOSCIUSKO, IN	44,474	58,100	48,153	48,506	46,154	46,154
LAGRANGE, IN	18,145	24,580	24,399	20,521	22,179	20,521
LAKE, IN	246,285	311,558	245,500	260,113	243,090	260,113
LA PORTE, IN	60,739	78,812	60,337	65,798	68,606	60,337
LAWRENCE, IN	22,348	27,771	21,574	23,185	20,671	20,671
MADISON, IN	59,619	67,907	53,265	56,694	**50,863**	50,863
MARION, IN	719,780	961,769	746,771	802,961	774,437	802,961
MARSHALL, IN	26,192	32,959	30,320	27,517	28,825	30,320
MARTIN, IN	8,728	10,204	7,897	8,519	**7,540**	7,540

NAME	Woods & Poole		Total Population Driven*	2030 share**	30-yr Population Change***	BLA Proposed
	July 1, 2000	July 1, 2030	July 1, 2030	July 1, 2030	July 1, 2030	July 1, 2030
MIAMI, IN	15,334	19,531	13,704	16,306	**13,085**	13,085
MONROE, IN	78,827	118,871	93,303	99,243	93,768	93,303
MONTGOMERY, IN	22,854	30,032	23,622	25,073	23,340	23,340
MORGAN, IN	20,788	28,634	28,618	23,906	26,169	28,618
NEWTON, IN	5,608	6,132	5,395	5,119	5,145	5,145
NOBLE, IN	28,146	37,186	31,245	31,046	29,309	31,046
OHIO, IN	2,824	5,027	3,042	4,197	3,440	3,042
ORANGE, IN	9,276	10,227	9,772	8,538	9,217	9,772
OWEN, IN	6,997	10,689	7,914	8,924	7,579	7,579
PARKE, IN	5,871	7,375	5,522	6,157	**5,273**	5,273
PERRY, IN	8,420	10,158	7,796	8,481	**7,444**	7,444
PIKE, IN	4,252	5,507	4,254	4,598	4,498	4,254
PORTER, IN	70,834	107,785	95,977	89,987	93,127	95,977
POSEY, IN	13,812	17,075	14,568	14,256	15,605	14,568
PULASKI, IN	6,931	8,369	6,855	6,987	6,640	6,640
PUTNAM, IN	17,499	25,619	19,516	21,389	18,468	18,468
RANDOLPH, IN	11,784	11,909	10,688	9,943	**10,206**	10,206
RIPLEY, IN	17,027	25,181	18,777	21,023	19,398	18,777
RUSH, IN	8,685	11,629	7,458	9,709	**7,122**	7,122
ST. JOSEPH, IN	161,646	198,043	167,811	165,342	164,670	167,811
SCOTT, IN	9,914	13,250	11,088	11,062	10,571	10,571
SHELBY, IN	23,060	29,083	23,398	24,281	22,902	22,902
SPENCER, IN	11,385	13,301	10,903	11,105	10,415	10,415
STARKE, IN	6,946	7,211	6,737	6,020	6,375	6,020
STEUBEN, IN	22,181	29,061	23,769	24,262	22,292	22,292
SULLIVAN, IN	8,243	11,637	8,489	9,715	9,801	8,489
SWITZERLAND, IN	3,184	6,923	3,793	5,780	4,319	3,793
TIPPECANOE, IN	99,665	142,057	130,006	118,600	129,830	130,006
TIPTON, IN	6,478	8,004	6,019	6,682	**5,748**	5,748
UNION, IN	2,789	3,712	2,695	3,099	2,604	2,604
VANDERBURGH, IN	130,031	170,102	131,530	142,015	155,461	155,461
VERMILLION, IN	6,862	8,445	6,181	7,051	**5,902**	5,902
VIGO, IN	64,767	81,618	61,296	68,141	**58,532**	68,141
WABASH, IN	20,432	23,723	19,229	19,806	**18,362**	18,362
WARREN, IN	2,900	3,452	2,684	2,882	**2,563**	2,563
WARRICK, IN	18,783	26,811	24,352	22,384	24,503	22,384
WASHINGTON, IN	10,769	14,055	12,127	11,734	11,426	11,426
WAYNE, IN	44,754	57,694	38,496	48,168	**36,759**	36,759
WELLS, IN	16,039	20,460	15,867	17,082	15,499	15,499
WHITE, IN	14,358	15,224	15,646	12,710	13,914	12,710
WHITLEY, IN	16,226	18,915	19,227	15,792	17,287	17,287

Notes: * 2030 population X (2000 employment/2000 population) X [laborforce participation ratio decline (0.575/0.605) X 1.0070278]
** W&P 2030 County employment/W&P 2030 Indiana employment X REMI 2030 Indiana employment
*** [2000 employment + (W&P employment change 2000 to 2030) X (proposed population change 2000 to 2030/W&P population change 2000 to 2030)] X [laborforce participation ratio decline (0.575/0.605) X 0.96]
default to total population comparison if negatives in population change (bold red)

The proposed forecasts were offered for reviewed by INDOT, the MPO's, the RPO's, and other interested parties together with the population forecasts. In response to comments, BLA made some minor alterations to and shifts between the county forecasts to arrive at the final values displayed in **Table 37**.

Table 37. Adopted County Total Employment Forecasts

NAME	Employment in TAZ			NAME	Employment in TAZ		
	2000	2015	2030		2000	2015	2030
INDIANA	**3,590,465**	**3,906,590**	**4,222,714**				
ADAMS, IN	21,409	24,006	26,602	LAWRENCE, IN	21,117	20,808	20,498
ALLEN, IN	230,660	257,228	283,796	MADISON, IN	58,367	60,342	62,316
BARTHOLOMEW, IN	52,219	58,061	63,902	MARION, IN	720,335	755,774	791,213
BENTON, IN	4,270	4,135	3,999	MARSHALL, IN	24,825	27,526	30,227
BLACKFORD, IN	6,076	5,588	5,100	MARTIN, IN	8,281	7,892	7,502
BOONE, IN	22,501	30,286	38,070	MIAMI, IN	14,398	13,698	12,998
BROWN, IN	6,087	6,244	6,401	MONROE, IN	78,190	89,305	100,419
CARROLL, IN	9,771	10,435	11,099	MONTGOMERY, IN	21,778	22,991	24,203
CASS, IN	21,535	21,418	21,301	MORGAN, IN	19,966	24,317	28,668
CLARK, IN	57,868	65,184	72,499	NEWTON, IN	4,950	5,024	5,098
CLAY, IN	11,786	12,142	12,498	NOBLE, IN	26,701	28,950	31,198
CLINTON, IN	14,457	15,380	16,303	OHIO, IN	2,569	2,833	3,097
CRAWFORD, IN	3,615	4,308	5,000	ORANGE, IN	8,636	8,619	8,602
DAVIESS, IN	14,484	15,793	17,101	OWEN, IN	6,403	6,951	7,499
DEARBORN, IN	20,191	25,494	30,797	PARKE, IN	5,117	5,159	5,201
DECATUR, IN	17,279	18,041	18,802	PERRY, IN	8,064	7,731	7,398
DE KALB, IN	27,202	31,301	35,400	PIKE, IN	3,792	3,997	4,201
DELAWARE, IN	68,622	72,715	76,808	PORTER, IN	69,810	73,819	77,827
DUBOIS, IN	34,496	37,249	40,001	POSEY, IN	13,066	13,924	14,781
ELKHART, IN	146,273	163,387	180,501	PULASKI, IN	5,973	6,287	6,601
FAYETTE, IN	13,278	12,639	11,999	PUTNAM, IN	16,370	17,335	18,299
FLOYD, IN	36,376	40,487	44,598	RANDOLPH, IN	10,602	10,303	10,003
FOUNTAIN, IN	7,758	7,880	8,001	RIPLEY, IN	16,205	17,452	18,699
FRANKLIN, IN	6,215	7,058	7,900	RUSH, IN	7,635	7,317	6,999
FULTON, IN	10,225	10,513	10,801	ST. JOSEPH, IN	161,788	170,598	179,408
GIBSON, IN	16,292	18,107	19,921	SCOTT, IN	9,443	9,971	10,499
GRANT, IN	37,630	34,115	30,599	SHELBY, IN	21,937	22,345	22,752
GREENE, IN	11,601	11,601	11,601	SPENCER, IN	10,432	10,367	10,301
HAMILTON, IN	105,619	145,400	185,180	STARKE, IN	6,308	6,204	6,100
HANCOCK, IN	23,231	30,923	38,614	STEUBEN, IN	21,443	22,574	23,704
HARRISON, IN	15,657	19,630	23,603	SULLIVAN, IN	7,699	8,101	8,502
HENDRICKS, IN	44,816	70,662	96,507	SWITZERLAND, IN	2,572	3,186	3,800
HENRY, IN	19,831	18,665	17,499	TIPPECANOE, IN	98,094	116,997	135,900
HOWARD, IN	57,236	58,618	59,999	TIPTON, IN	5,756	5,728	5,700
HUNTINGTON, IN	20,436	22,719	25,001	UNION, IN	2,426	2,514	2,601
JACKSON, IN	25,111	26,055	26,998	VANDERBURGH, IN	129,621	140,208	150,794
JASPER, IN	14,909	15,904	16,898	VERMILLION, IN	6,493	6,196	5,898

NAME	Employment in TAZ			NAME	Employment in TAZ		
	2000	2015	2030		2000	2015	2030
JAY, IN	9,421	9,160	8,898	VIGO, IN	64,001	66,250	68,499
JEFFERSON, IN	16,930	18,267	19,604	WABASH, IN	19,338	18,769	18,199
JENNINGS, IN	11,256	12,678	14,100	WARREN, IN	2,338	2,469	2,600
JOHNSON, IN	54,289	74,033	93,777	WARRICK, IN	18,167	20,378	22,589
KNOX, IN	22,006	20,904	19,801	WASHINGTON, IN	9,609	10,454	11,299
KOSCIUSKO, IN	42,414	45,256	48,097	WAYNE, IN	43,653	41,028	38,402
LAGRANGE, IN	16,202	18,403	20,603	WELLS, IN	14,989	16,745	18,501
LAKE, IN	243,627	248,228	252,828	WHITE, IN	13,718	14,011	14,303
LA PORTE, IN	58,714	59,462	60,210	WHITLEY, IN	15,609	17,404	19,199

Similarly to the population the final forecast employment growth (or decline) was then allocated among the TAZ in each county using a regression model. This regression model was developed by regressing the year 2000 employment against other year 2000 socioeconomic variables (since comparable historic employment data was unavailable) and actually predicted total employment. The independent regressor variables included Total Population, Total Households, Population Density, Aggregate Personal Income, Presence of Airport, Presence of Hospital, University Enrollment, Travel Time to Nearest City Center, Travel Time to Nearest Major Arterial, Travel Time to Nearest Freeway, Accessibility to Intermodal Freight Facilities, Accessibility to Households, Accessibility to Population, Accessibility to University Enrollment, and Accessibility to Wealth (by place of residence). The regression equation included several terms including these variables and their interactions. Each term had an F statistic which resulted in a significance of 0.03 or better. The r-squared for the regression equation was 0.579. The model was used to estimate the 2000 employment and the 2030 employment. The estimated change in employment from the regression model was expressed as a change in the zonal share of the county total employment. One third of this change in zonal share of county total employment was then applied to the zone's actual year 2000 share of county total employment. The resulting shares were applied to the forecast county control total to breakout the total employment forecast to the zones. Only one third of the modeled shift in zonal share of county employment predicted by the regression model was applied to bias the final allocation towards the existing distribution of employment given the inherent uncertainty in land use forecasting and the r-squared for the regression model.

Once the total employment had been allocated to the zones, this employment had to be broken out into the various industrial categories. Shifts in industry groups' shares of total employment at the county level were taken from Woods & Poole and applied to the forecasted county total employment to produce county control totals for each industry category. These county control totals by industry category together with the total employment allocation to the TAZ provided the marginals necessary to perform a Fratar procedure for each county using the year 2000 distribution of employment by TAZ by industry category as the seed distribution. The Fratar produced a distribution of employment by TAZ by industry category for each county which conformed to both the zonal total employments and the county control totals for the industry groups.

Employment forecasts for counties outside Indiana were taken directly from Woods & Poole. The distribution of employment among TAZ within the few counties with multiple TAZ outside Indiana was held constant.

C. OTHER VARIABLES

In addition to population and employment, the ISTDM relies on households as a key socioeconomic variable and with the implementation of the stratification curves, is now also sensitive to average household size, average household auto ownership, and average household income. These variables were also therefore forecast for the model area.

Average household size at the zonal level was uniformly adjusted throughout each county to agree with the overall average household size for that county forecast by Woods & Poole. Holding out the population in group quarters, which was assumed to be constant, the forecast average household size was then used to convert the forecast zonal population into households. Average (mean) household income was forecast similarly to average household size by uniformly adjusting the zonal averages to produce the county average forecast by Woods & Poole. Income was treated in constant dollars since the trip-making characteristics were thought to be related to real rather than nominal wealth.

Since there were no known forecasts of vehicle ownership available, this variable was forecast using the variables already forecast and the following regression equation developed using the base year 2000 data:

$$\overline{HHAO} = 0.405\overline{HHSZ} + 0.472(\overline{HHSZ} * \overline{HHINC}) + 0.097\overline{HHINC}$$

where,

$\overline{HHAO}$ = average household auto ownership,

$\overline{HHSZ}$ = average household size, and

$\overline{HHINC}$ = mean household income.

The r-squared for the regression equation was 0.987.